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PHYSICS.—*High voltage.*[1]

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While there is much truth in the statement that necessity is the mother of invention, it has often been pointed out that it is far from true that necessity is the mother of discovery. Discoveries come often most unexpectedly, in the pursuit of knowledge by the curious and observant. The great background of natural phenomena which have thus been discovered form an immense reservoir from which may be drawn natural laws or combinations of phenomena which can be made to work for the solution of men's needs or desires when necessity arises.

One of the most excellent examples of the fact that necessity is the mother of invention is found in the great number of applications of science which were made during the past war to cope with situations which never before had challenged the ingenuity of man. Such situations were the detection and location of submarines or of airplanes flying by night. There were also the location of underground mining operations or of enemy artillery by sound, or the direction of counter-battery artillery fire, also by sound. Such examples could be multiplied almost indefinitely, but the interesting feature of them all is that every one was handled by the application of some scientific phenomenon which had been known in the laboratory for many years. The necessities of war brought forth the means of applying these phenomena for particular purposes.

It is to a very recent example of this natural sequence of events that I will call your attention tonight, an example taken from the field of electricity, the chosen field of Joseph Henry in whose honor

[1] The third Joseph Henry lecture delivered before the Philosophical Society of Washington on March 11, 1933. Received April 6, 1933.

this lecture has been named. It is a modern application of one of the oldest branches of electricity, a branch so old that some ultramodern textbook writers have advocated omitting it entirely from textbooks on account of the academic and impractical character of its subject matter. But let me first lay the groundwork for this new development in the field of high-voltage electricity.

While electricity can be produced in a variety of ways, and it was some time in the history of the subject before it was realized that the electricity was the same kind of thing in all of these cases, nevertheless there are but three principal means of generating electricity. The first is static electricity, first discovered by Thales of Miletus as early as 600 B.C. Thales found that amber, when rubbed against other substances, had the power of attracting fragments of straw or leaves or feathers. In fact the word electricity is derived from the Greek word electrum meaning amber, and was first so used by William Gilbert in about 1600.

The second great step in the production of electricity was the invention by Volta of the Voltaic cell in 1799, and from that time until the time of Faraday in 1831, the great development of electricity was in the production of batteries of various kinds. Volta was able to generate several hundred volts by piling up alternate layers of copper and zinc, separated by paper which had been moistened with acid thus creating, in effect, a battery with a large number of cells in series.

When in 1831 Faraday made the discovery of electromagnetic induction and about the same time Joseph Henry discovered self-induction and independently repeated a number of Faraday's discoveries in mutual induction, the modern science of electricity and art of electrical engineering were born.

It is a striking fact, which perhaps we do not stop to think about, that this so-called electrical age has grown up during a period of one working lifetime, since men like Elihu Thomson are still living and men like Edison have just died, who built upon these scientific discoveries of Faraday and of Henry the modern art of electrical engineering.

With the development of electro-magnetic devices, dynamos, motors and transformers, the use of batteries except for very special cases has largely been discontinued. Static electricity, which had been developed from the study of frictional charges and charges of conductors by induction, was relegated almost to the field of scientific but useless curiosities. The efficiency of electromagnetic generating apparatus has been developed to a remarkable degree, so that, for the

practical purposes of our industrial needs and our home needs, the modern science of electricity has appeared to be eminently satisfactory.

It is true that there have been some other new developments of first importance in the electrical field, notably electronic devices, such as radio tube detectors, amplifiers and transmitters or devices which operate with ionization of gases, such as the mercury-arc rectifier and the glow discharge tube. These things, however, are more in the nature of electrical instruments or electrical control devices and it still remains true that the production and distribution of electricity are basically carried on by means of the electro-magnetic induction devices developed from the work of Faraday and Henry.

Let us first follow the development of high voltage by electromagnetic induction. In this as in all other fields the first developments were crude, as was necessarily the case because instruments and methods had not been developed and everything had to be taken up *de novo*. When Joseph Henry wished to build his great magnet with several coils of wire, he had first to invent insulated wire, which he did by wrapping strips of his wife's dresses and petticoats with shellac around the wire. When Henry wished to measure the voltage of the current produced in a step-up transformer, he had no ammeter or voltmeter capable of detecting the small current at high voltage and had to substitute for them the students in his class, judging the voltage by the number of students who could be shocked when connected hand to hand in series across the terminals of the secondary of his transformer. Thus a voltage that would shock thirty students he estimated to be twice as high as one which would shock fifteen students, and in this way he was able to arrive at a very crude but correct idea of the relationship between the number of turns of wire in the secondary of a transformer and the voltage which was produced therein.

The story is told of a striking lecture demonstration given by Henry while at Princeton. He hung a secondary coil of a large number of turns of wire on the inside wall of his classroom and had the students of his class join hands in series across the terminal of the coil. The primary coil of this transformer was concealed from the students, being suspended on the outer wall of the building from wires passing out through an attic window and connected with a large Voltaic battery in the attic. When Henry rapped against the wall his assistant in the attic plunged the copper and zinc battery plates into the acid, thus sending a current through the primary, which induced a high voltage in the secondary and shocked the students of his class.

It is probable that Henry, burdened as he was with administrative

duties and the difficulties of finding the means wherewith to carry on his experiments did not realize so clearly as did his contemporary, Faraday, the ultimate practical value of these things which he was doing. Faraday, when once asked by the King, "What is the use of these things?" replied, "Your Majesty, of what use is a baby?" And another time when he was asked by the Prime Minister this same question, "Of what use are these things which you are doing?" he replied, "Your Excellency, some day you may be able to tax these things." Henry, however, was so wrapped up in his scientific pursuits that he gave little thought to the possible practical application of his work. It is said that when he was once urged to press his claim as inventor of the telegraph and other instruments, he replied that there were far too many interesting things to be done in the laboratory to permit him to take time with such matters.

There has been a practical urge for the development of high voltage power from three different points of view. The first and most important of these is for the transmission of electric power over large distances. It is much more economical to transmit power at high voltage and small current than at low voltage with large current because the resistance losses depend upon the current and not the voltage. For this reason, the voltage of high power transmission lines has continually risen from first a few hundred volts, then a few thousand, not many years ago sixty thousand, and now upwards of two hundred thousand volts. The losses of power due to heating of the wire from the flow of current are such that, according to a practical rule, it is not economical to transmit electrical power farther than one mile for every thousand volts. From this we see that a modern two hundred thousand volt transmission line could be economically used to transfer power from the power generating station to distances of about two hundred miles but beyond these distances such transmission of power is not economical. For that reason, in any area requiring the use of electricity, power generating stations must be located at distances of not more than two hundred miles from each other.

The question may be asked as to why the voltage is not raised still higher than two hundred thousand volts, and the answer to this is found in the fact that with higher voltages the electric field in the air surrounding the wire becomes so intense as to ionize the air, causing a leakage of electricity from the wire into the air in the form of an electric discharge known as a corona. It is this phenomenon of corona which sets the practical upper limit to the voltage which can be used for transmission.

It is not feasible to generate directly voltages in the range of several hundred thousand volts because the difficulty of insulation becomes too great, and an electric dynamo with insulation adequate to withstand even several thousand volts would have to be so large, to include the necessary insulation, as to be unwieldy and inefficient. Consequently, the power is generated at relatively low voltage, usually a few hundred volts in alternating current and this is sent through a step-up transformer insulated in oil in which the secondary has a hundred or a thousand times more turns of wire than the primary. In this secondary coil the very high voltage is generated for transmission over the power lines. Then at the other end of the line the power is fed through a similar transformer in the reverse order and comes out of that secondary as a very large current at relatively small voltage.

There has been no really fundamental difficulty to be overcome in these power transmission lines, although there have been very many interesting problems of science and engineering to be solved. The proper design of a transformer to be efficient and to be sufficiently well insulated is one problem. Perhaps the most difficult problem has been that of proper switching devices so that these high-voltage currents can be started and stopped without excessive arcing at the switches. It is such developments as these which have made the great generating stations at Niagara Falls and the many other hydro-electric or steam-electric generating stations such an important feature in our present industrial life.

The second thing which has stimulated high voltage developments of the electro-magnetic type has been the x-ray. For ordinary purposes, from thirty thousand to one hundred thousand volts are adequate for either diagnostic or therapeutic purposes. Of recent years, however, in the endeavor to find the most effective methods of treating internal cancerous growth there has been an increasing desire to go to much higher voltages and consequently x-ray tubes operating on as much as a million volts have been developed at the General Electric Company, at the California Institute of Technology, and elsewhere.

To generate the high voltage power for these x-ray tubes, recourse has been had to transformers connected in series, the primary of one transformer being connected with the secondary of the other, and all transformers after the first being insulated. By such means, large power can be delivered and high voltages obtained, although a million volts appears to be about the practical limit because there are parasitic currents known as charging currents which drain a great deal of

energy uselessly from the system when an alternating or varying current is used at such high voltages. Furthermore, the equipment becomes tremendously expensive on account of the requirements for insulation.

The third thing which has led to high voltage developments of the electro-magnetic induction type has been the study of the effect of lightning on transmission lines and the desire of electrical engineers to duplicate as nearly as possible the effect of lightning by means of high-voltage sources for laboratory study. For this purpose there has been developed the impulse generator, in which a series of condensers capable of storing electric charge at high voltage are charged in parallel from a high-voltage transformer and are then connected in series so that the overall voltage which is delivered is the sum of the voltages across the separate condensers. By such means impulsive or momentary voltages of ten or fifteen million volts have been obtained. These are exactly right for studying transient effects like those of lightning, but the impulse generator is inherently incapable of serving properly any purpose which requires a steady and reasonably constant source of high voltage. The discharge in this impulse generator lasts only a few hundred thousandths or millionths of a second.

This impulse generator represents the peak of high voltage accomplishment by the electro-magnetic method and you will notice that this is accomplished by combining with the electro-magnetic device, namely the step-up transformer, a series of condensers which are essentially electro-static instruments.

Let us return now from the high-voltage developments, based on principles of electro-magnetism, to the historically earlier type of electric generation which falls within the general field known as electro-statics. The characteristic of these devices has been the relative ease of producing high voltages, but with an exceedingly minute quantity of electricity.

The first electrical machines of which we have any knowledge were frictional electrical machines constructed about 1663 by Otto von Guricke. They consisted of globes of sulphur made to rotate about an axis so as to rub against the hands of persons held against them. In this way the globe of sulphur became electrically charged and the charge of the opposite sign appeared on the person who touched the globe. Isaac Newton appears to have been the first person to use a glass globe instead of sulphur, but it was Ramsden in 1768 who really constructed the first object which might really be called an electrical generating machine.

The Ramsden machine consists of a glass plate which can be rotated by a winch, and which passes with rubbing contact between two leather pads. By friction the glass becomes positively charged and the pads negatively charged. These positive charges are taken off the glass disk as it passes in rotation between combs of sharp points. Similarly the negative electricity from the pads is collected from them and delivered to another terminal. For a number of years the only development of the art of electrical generation consisted in finding various materials which might be put on the glass or on the leather pads to increase their effectiveness in separating frictional electricity.

A later development of a frictional machine is that invented by Lord Armstrong of Newcastle, England, in 1841. Lord Armstrong was experimenting with steam boilers. By accident one of his assistants received an electric shock when he touched a piece of metal against which a jet of steam from a leaky boiler was striking. This led Lord Armstrong to further experiments leading to the steam electro-static generator. The action of this generator consisted in blowing drops of condensed steam, by the steam pressure, out through a series of nozzles against a neighboring metal plate. The droplets of water were charged by frictional contact against the walls of the nozzles. The electrical power was created by the work done in moving the charged droplets against the electric field which developed between the nozzle and the plate on which the droplets struck, and of course this power was in turn derived from the driving power of the steam which carried the droplets out and away from the nozzle.

Another whole series of electro-static generators was built upon the principle of electro-static induction. Perhaps the simplest of these was the Belli doubler, which was devised in 1831 and operated on the same principle as a later device designed by Lord Kelvin and better known as the Kelvin Replenisher, described by him in 1872. This action is shown schematically in Fig. 1. When the rotating member with the insulated plates E and F is at the position shown, positive and negative charges are separated from the connecting wire, which brushes lightly against E and F, by means of the electro-static forces arising from the charges on the neighboring metal armatures C and D. As the rotating arm turns and breaks contact with these brushes the charges are carried on E and F and, when they touch the springs C and D respectively, these charges are communicated to the armatures, thus increasing the charge already existing on these armatures. Then at the next contact with the brushes at E and F the process is repeated. Consequently the charge on the armatures continually

builds up until it reaches such magnitude, or rather until the voltage rises so high that the charge leaks away as fast as it is produced, leaking away either through the insulation or by a corona discharge produced by breakdown of the surrounding air.

A large variety of instruments, some simple and some very complicated, have been developed to carry on the idea of the Belli doubler in a more efficient manner. Such devices were devised by Varley in 1860, by Toepler in 1865 and by Holtz between 1864 and 1880, but by far the most successful of these devices is the well-known Wimshurst machine which was first invented in about 1878. This machine is well-known to everybody, I think, as the "influence machine" whose action may be described as follows:

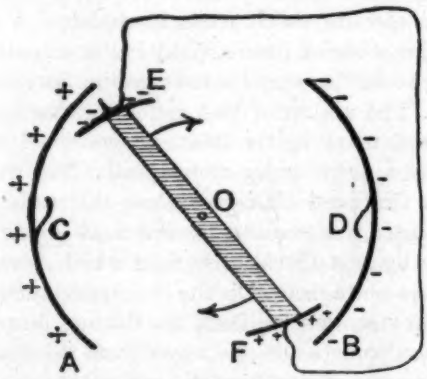


Figure 1.—Schematic diagram of Kelvin Replenisher.

Imagine that, in some way or other such as by friction, a small negative charge is located on the metal sector of the rotating disk opposite the point *C* of Fig. 2. This negative charge will induce the separation of positive and negative electricity in the metal rod *CD*, drawing positive charge to the point *C* and forcing negative charge to the point *D*. At these two points the charges are collected on the metal sectors of the second glass disk which is rotating in the opposite direction. Thus all the metal sectors to the right of *C* carry positive charge collected from *C* and they all deliver it to the sharp needle point at *F*.

At the same time, these positive charges on the metal sectors to the right of *C* will similarly induce negative charges in the metal rod *AB*, which charges will be deposited on the metal sector to the left

of A and will in their turn be collected by the sharp point at E. Thus the process is a continuous one, E and F collecting negative and positive electricity, respectively, from the metal sectors on both of the revolving disks. By having a multiplicity of revolving disks these Wimshurst machines may be made to deliver a considerable amount

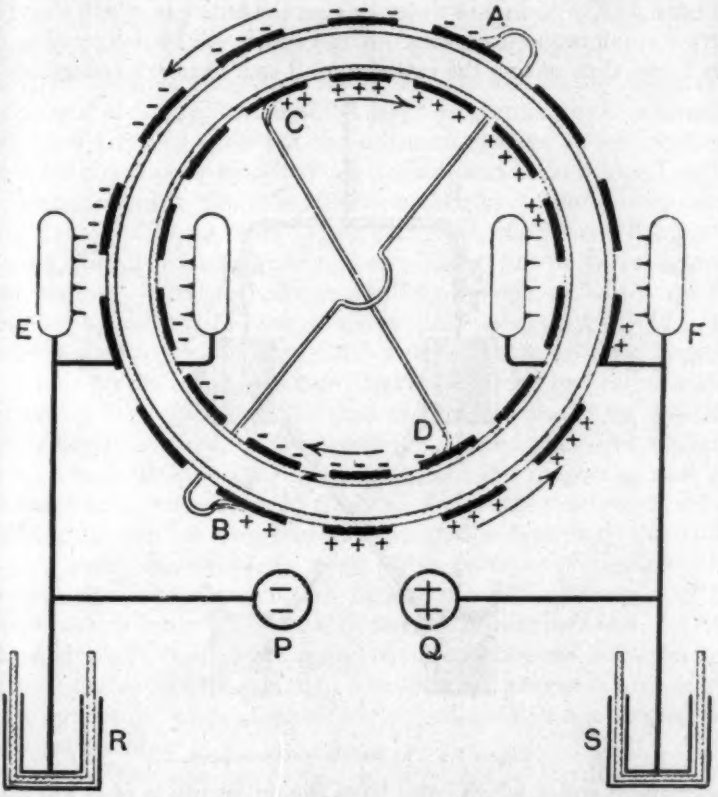


Figure 2.—Schematic diagram of Wimshurst influence machine.

of power and were in fact at one time quite largely used in the x-ray art until they were supplanted by the more powerful and much more convenient electro-magnetic induction devices described previously, including step-up transformers, induction coils and the like.

One of the most ingenious types of electrostatic induction machines is the famous Kelvin water-dropper which is shown in Fig. 3. Here

perhaps more easily than in any of the other induction machines can be seen the way in which a small charge once produced may result in the continual building up of an indefinitely large charge, if the arrangement of apparatus and connections are suitably arranged. Assume for a moment that for some cause, such as friction of the wind or anything else, there happens to be a small charge on the cylinder *A*. Every drop of water leaving the outlet in *A* will therefore carry a small induced negative charge which will be delivered to the cup below thus raising the cylinder at *B* to a negative charge. All of

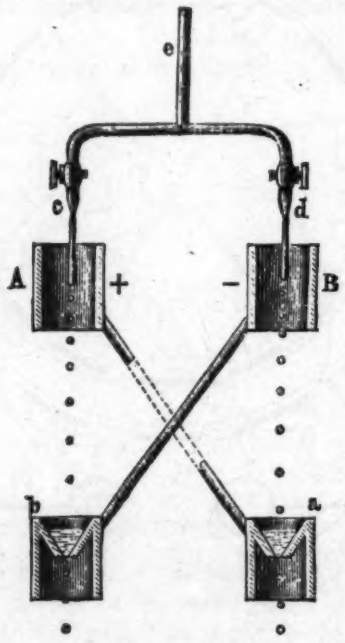


Figure 3.—The Kelvin water-dropper.

the drops of water which come from the outlet inside of *B* will therefore carry the positive charges which will be collected in the trap below and serve still further to increase the positive charge on *A*. So the process goes on, the charges building up until through leakage or through a corona discharge to the air, they leak away as fast as produced.

At this point I am minded to make a confession regarding my first experiment in physics. I conceived the idea of producing electrolysis by the use of gravitational energy alone, and set up a device some-

what similar to the Kelvin water-dropper. My device consisted of drops of copper sulphate coming from an outlet like that in the cylinder *A* and falling into a platinum funnel like that directly below *A*. I charged the cylinder *A* with a large negative charge from a static machine and this charge remained on the cylinder, which was well insulated. Consequently, every drop of copper sulphate which dropped carried an induced positive charge and delivered it to the funnel *b* which was earthed. This excess positive charge would of course be in the form of copper ions which would be deposited on the platinum in the process of neutralization of the drop. After running the apparatus for an hour or so, I looked at the platinum cylinder to see whether I could see any copper deposited on its inside and finding none I set the apparatus going in the late afternoon and let it run automatically until the following morning. Again examining the funnel, I found no deposit of copper and, somewhat surprised, I sat down to figure. I soon discovered that the copper would be present in far too small a quantity to detect. In fact, if every drop were charged with the largest amount of electricity which it could carry without losing it by corona to the surrounding air, and if the drops had fallen as fast as possible beginning with the time of Christ, I would by this time have collected barely enough copper to be shown by the most sensitive known chemical test. This little experience illustrates the vast difference in magnitude between the kind of currents that we are accustomed to deal with in electromagnetic induction devices, dynamos and motors, and these relatively very feeble currents of electrostatics. These drops were charged with high electrostatic voltage and the device was a fairly efficient electrostatic generator, and yet two thousand years would have been required to deposit an amount of copper such as would appear in a fraction of a second with only a moderate current of the type which we ordinarily use in electromagnetic instruments.

In recent years an interesting development of the Kelvin water-dropper has been proposed by Doctor Swann of the Bartol Research Laboratory in which the water drops are replaced by steel balls which fall under the action of gravity, and in order to make the process continuous, there is the suggestion whereby these balls may be carried back again to the upper container by means of magnetic control. In this way, the succession of falling balls behaves somewhat like a continuous belt containing metal sections separated by insulated regions of air and driven by gravity. In the absence of leakage this kind of a generator should be capable of developing such a high voltage

that the electrostatic attraction of the falling balls would just compensate gravity. This would be an extremely high voltage such as could be obtained only if the apparatus were operating in a vacuum, and in fact Dr. Swann suggests that it may be operated in this manner.

With this historic survey of electrostatic generators, let me now return to the text of my address, "Necessity is the mother of invention." Until very recently there was no compelling need to force physicists to seek ever higher and higher voltages in electrical-generating devices. Their needs were met by existing devices of the electromagnetic type. Within the past dozen years, however, it has become evident that a whole new range of fundamental investigation into the properties of atoms will be opened up by a suitable source of high potentials.

This new inducement may be said to have arisen with Rutherford's discovery that it is possible to transmute one chemical element into another by bombarding it by the fast electrified particles known as alpha particles which are spontaneously given off by radio-active materials in the process of their disintegration. These brilliant experiments opened up a whole range of new explorations into the structure of the atomic nucleus, and stimulated the imagination of scientists in regard to what might be done if only they had available some more powerful and better controllable source of high-speed missiles to shoot at the atomic nuclei. The alpha particles from radium do have tremendous velocities but they are relatively few in number and all the radium that could conceivably be gathered together in the world would not produce a stream of electrified particles comparable to that which can be obtained in an ordinary discharge of electricity through a vacuum tube. If only the voltage as applied to a vacuum tube could be made high enough to give the ions in a vacuum tube speeds comparable with or even exceeding those of alpha particles from radium, what a powerful attack could be made upon the nucleus! Not only could particles in billion-fold larger numbers be used, but different kinds of particles could be tried, such as hydrogen-nuclei, helium-nuclei, lithium nuclei, neon-nuclei and so forth, and these could be given any desired speed up to the maximum limit determined by the highest voltage available. So for the past dozen years, thoughts of scientists have again been turned to means for producing ever and ever higher voltages.

It was to this end that the million-volt installation at the California Institute of Technology was designed. It was also to this end that a

system of high potential transformers and condensers was built by Cockcroft and Walton in Cambridge, with which they were the first successfully to disintegrate atoms by means of electrified particles produced from an artificial source and speeded up by an applied voltage. However, the necessities of the case have led to other suggestions for securing high voltages because the inherent limitations of electromagnetic induction devices lead to prohibitive expense and complexity if voltages much above a million volts are sought by such means.

There have thus been three very interesting new developments in the art of securing high voltages, or perhaps more generally, electrified particles with those speeds which would be acquired with tremendously high voltages. Of these, in order of apparent utility, are the devices of Brasch and Lange in Germany, of Lawrence at the University of California and of Van de Graaff at the Massachusetts Institute of Technology.

The greatest natural source of high voltage of which we have any knowledge is the thunderstorm. It is estimated that the voltages in lightning flashes frequently exceed a billion volts; consequently it was natural for Brasch and Lange to look to the lightning flash as a source of high potential and to set up what may be considered as a glorified Franklin kite. Their apparatus consisted of a pair of long cables suspended between mountain peaks in that region of the Alps where thunderstorms are most frequent. These cables may be thought of as huge wireless antennae for receiving the electrical impulses of nearby lightning flashes. This was an installation of real engineering proportions since the porcelain insulators alone at each end of the cable weighed upwards of two tons. The terminals of the two conducting cables consisted of large spheres, whose distance apart could be varied by drawing in or letting out cable. The voltage obtained was estimated by the sparking distance between these spheres and voltages were obtained ranging between eight and fifteen million volts.

Although the voltage was tremendously high, its erratic occurrence and uncontrollable nature has led Brasch and Lange to give it up in favor of somewhat more conventional means of producing their high voltage, and at present they are working with an impulse generator.

An extremely clever device is that invented by Professor Ernest Lawrence of the University of California by means of which electrified particles may be given energy characteristic of several millions of volts with the application of a much smaller voltage. The principle

is that of repeated impulses, analagous to the way by which the amplitude of swing of a child in a swing may be made very great by a succession of small pushes, properly timed. In Lawrence's apparatus, an oscillating voltage is applied to the ions, first in one direction and then in the other, while they are moving in approximately circular paths in a magnetic field and conditions are adjusted so that every time the voltage is applied the electrons are speeded up by just that

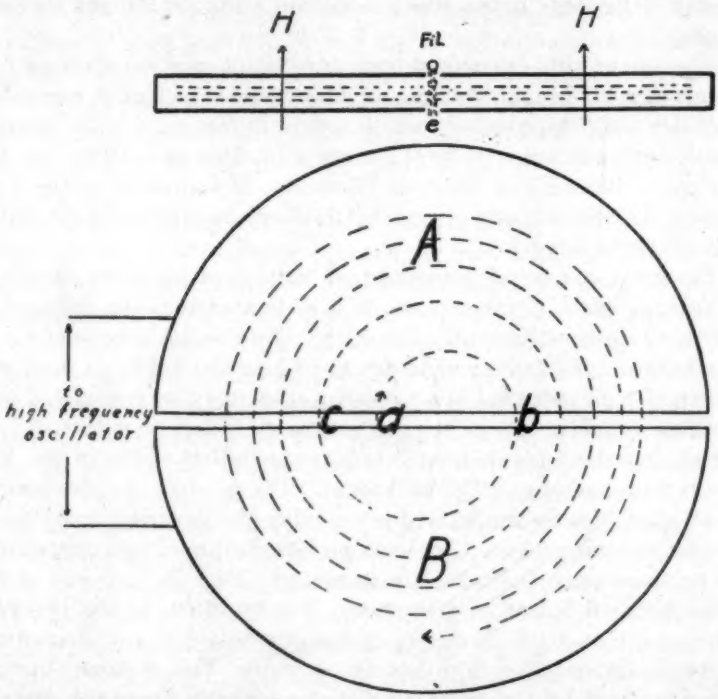


Figure 4.—Diagram of Professor Lawrence's apparatus for producing high-speed, electrified particles.

amount. Thus, by applying only a few thousand volts, protons have been obtained with energy corresponding to nearly two and a half million volts.

Fig. 4 shows a diagram of the apparatus. The protons or other ions are liberated, by a suitable device, near the centre of a flat hollow cylinder which is divided into two parts separated from each other. The oscillating high frequency voltage is applied to these two parts and at the same time the whole cylinder is placed between the poles

of a powerful magnet. An ion starting at *a* is pulled by the momentary electric field across the gap and it takes, in the magnetic field, a circular path around to *b*. The frequency is adjusted so that by the time time it reaches *b* the direction of the voltage has reversed so that the ion is again speeded up as it crosses *b* back into the half-cylinder from which it started. Then by the time it reaches *c* the voltage has again reversed to its original direction and it is given another push, and so on and so on. The few-thousand-volts push is given to the ion every time it crosses the gap. It proceeds in ever-widening circles attaining a speed limited only by the dimensions of the apparatus. With this device, Lawrence and his colleagues have reason for hoping that the speeds may ultimately be increased up to perhaps the equivalent of ten million volts.

The currents are not very large, being reported of the order of a thousandth of a microampere. Nevertheless, these currents are tremendous in comparison with anything which can be obtained from radioactive material and this source of high-speed, electrified particles will evidently be an important tool in nuclear investigation, as is in fact evident from very recent reports from Professor Lawrence's laboratory in which the experiments of Cockcroft and Walton in disintegrating lithium nuclei by means of high speed protons have been confirmed and extended.

In the construction of this apparatus, the largest magnet ever built in this country has been put into use.

We come now to what I believe to be the most important development that has ever taken place in the field of extremely high voltages, namely the Van de Graaff generator, invented by Dr. Van de Graaff, as a result of considerations which were developed while he was a Rhodes scholar in England and which first took shape in the form of physical laboratory experiments at Princeton and which are now being developed and extended in the laboratories of the Massachusetts Institute of Technology.

From every point of view it is advantageous for very high voltages to have direct uniform currents. Van de Graaff was therefore led to develop an electrostatic generator, since electrostatic methods yield directly a steady uni-directional voltage such as is desired. Maximum simplicity was sought in the design. The simplest terminal assembly appeared to be a sphere mounted on an insulating column. Since the sphere must be charged and since the process should be continuous, the charge carrier should approach the sphere, enter it, and, after depositing its charge inside should return parallel to its path of ap-

proach. This immediately suggested the action of a belt, a device long used for the transmission of mechanical power.

The logic of the situation therefore pointed directly to a generator consisting of a hollow spherical conducting terminal supported on an insulating column, a moving belt to carry electric charge to the sphere, a device for depositing the charge onto the belt in a region of low potential remote from the sphere, and a device for removing this charge from the belt inside the sphere and transferring it to the sphere. A refinement of these essentials was the addition of an induction device whereby charge of the opposite sign was carried by the belt on its return journey, thus doubling the current output. A second refinement consisted of a self-exciting charging device whereby the entire generator could be made to operate independently of any external source of electricity. Not only does this device attain the desired result in what appears to be the simplest possible manner, but it is also interesting to note that the energy transformations in its operations are exceedingly simple, consisting only in the transformation of the energy required to drive the belt into work done in separating and transferring electric charge from earth potential to sphere potential. Fig. 5 shows, schematically, the operation of this generator.

By this means electricity is continually conveyed to the spherical terminal, whose potential consequently rises until limited by the breakdown of the insulation of the air in the form of a corona discharge at the surface of the spheres. This breakdown voltage depends on the size of the sphere, being approximately 750,000 volts for a 2-ft. sphere and increasing to 5,000,000 volts for a 15-ft. sphere. Thus the attainable voltage depends upon the size of the spherical terminal.

The current, on the other hand, is simply equal to the rate at which electricity is carried to and from the sphere by means of the belts, and this in turn depends upon the size, speed and number of belts and the quantity of electricity which can be placed on unit area of the belt. This latter quantity is also limited by the breakdown voltage of the surrounding air, to an amount of about 5×10^{-9} coulombs per sq. cm. of belt area. Under these conditions it is readily shown that a belt running at 6000 ft. per minute could theoretically carry a maximum current of 150 microamperes per inch width of belt. Actually, the best adjustments have given about half of this theoretical maximum, probably because the breakdown strength of the air is reduced by the mechanism whereby charge is sprayed onto the belts.

Theory and practice also show that these belts may be placed as close together as is geometrically possible, in fact, practically in

contact, without interfering with their capacity to carry charge. By packing many belts together it is therefore possible to produce very sizeable currents. For example, a small laboratory model for demonstration purposes, constructed this year in the laboratories at Massachusetts Institute of Technology, develops one and one-half million volts between a pair of 2-ft. spherical terminals, and delivers a current of 600 microamperes carried on two 8-inch belts in each sphere.

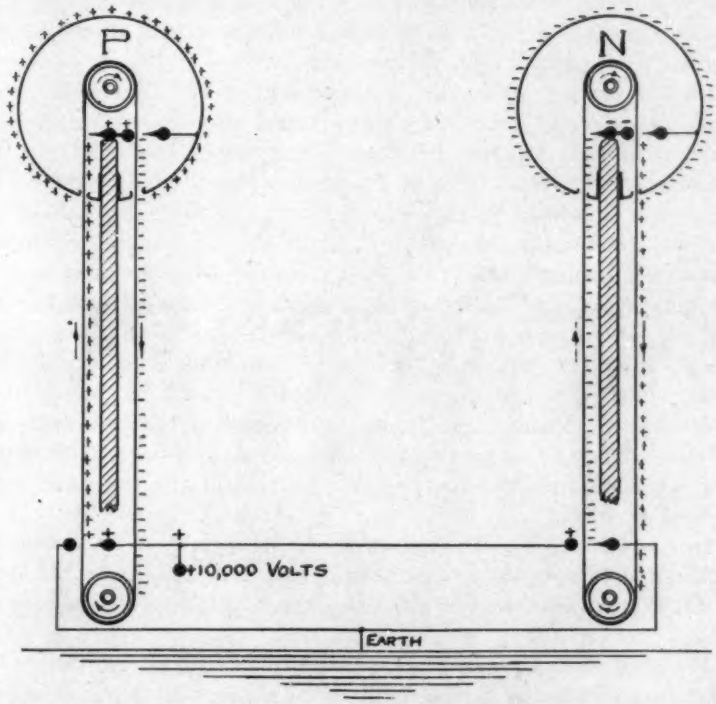


Figure 5.—Schematic diagram of Van de Graaff electrostatic generator.

Even in this small model the currents are approximately a million times greater than those which have been obtained in the high speed ion source designed by Lawrence.

The first model of such a generator which was actually constructed, was built in Princeton in the fall of 1929, being built out of a tin can, a silk ribbon, and a small motor, at no expense. This model developed 80,000 volts, being limited by the corona discharge from the edges of the can.

The next model was designed and built for operation in a vacuum tank for reasons to be outlined later.

The third model was built to give a quick and easy demonstration of the possibilities of the machine, using 2-ft. spherical terminals supported on pyrex rods, and supplied by current carried on silk belts $2\frac{1}{4}$ inches wide, driven by small motors. This apparatus was demonstrated successively in Princeton, New York, Washington, Boston, and elsewhere. Although built at a total cost of less than $100, it developed more than twice as high a voltage as any direct current generator of which we have knowledge.

Encouraged by the success of this model, plans were immediately made for the construction of as large a generator as seemed practical for operation in air, the limitation being placed by the size of the house in which it must operate. The largest place available was a dock built for a Goodyear dirigible on the estate of Colonel E. H. R. Green at South Dartmouth, Massachusetts, and which Colonel Green kindly put at the disposal of the Institute. Ten million volts was selected as the highest voltage which could be used in a building of this size without excessive loss of current through the air to the roof and walls. For this voltage, therefore, there has been built a generator with 15-ft. spherical terminals made of welded aluminum, mounted on 24-ft. textolite insulating columns in the form of 6-ft. cylinders, and carried on large fabricated steel trucks, running on a 14-ft. gauge railway track in order to vary the position of the terminals when desired.

In this construction the Research Corporation gave invaluable aid through assistance in the engineering drawings and through a grant of $10,000 which defrayed approximately half the cost of the generator.

Fig. 6 is a photograph of this generator, taken on the day before Christmas. In using this generator for experimental purposes it is planned to use the inside of the spheres as laboratory rooms, and to mount the discharge tube, suitably designed for producing high speed ions, between two spheres.

Every feature in the construction and operation of this large generator has gone as expected and a few days ago the first belt was put into operation and voltage generated as expected. This belt is made of paper 3 ft. wide and running at about 5000 ft. per minute. The initial trials gave an output of 600 microamperes, and previous experience indicates that with the proper adjustments this output may be increased to a milliampere. The design of the apparatus is

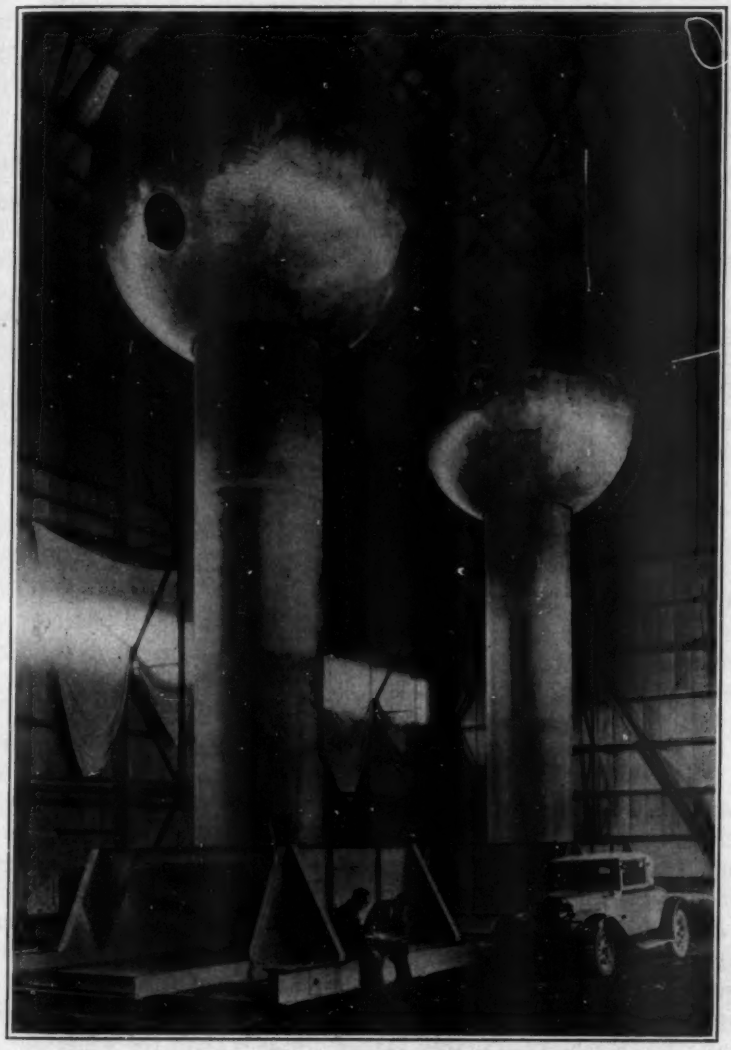


Figure 6.—The large Van de Graaff generator of the Massachusetts Institute of Technology.

such that a large number of belts may be made to operate in parallel, so that there will be no difficulty whatsoever in securing an output of between a tenth and a hundredth of an ampere if such large currents become desirable. It will be noted, however, that if currents as large as a tenth of an ampere are used at 10,000,000 volts, the generator will be delivering 1000 kilowatts!

The enormous possibilities of this machine become evident when we compare a possible input of 1000 kilowatts in the form of 10,000,000 volt electrified particles, with the sources which up to the present have been available for experiments on atomic disintegration and which have been principally small amounts of radioactive material.

We come now to a very interesting aspect of this type of generator, namely, the influence of the surrounding insulating medium. If the generator is placed in some medium whose electrical breakdown strength is greater than that of air, then the voltage and the current both increase proportionately and the power output increases as the square of the breakdown strength. The two media most convenient are either some gas such as air at high pressure, or a vacuum. With gas at high pressure, the breakdown strength is approximately proportional to the pressure, so that the operation of a generator in a tank of gas at 30 atmospheres pressure should give 30 times the voltage, 30 times the current and 900 times the power of the same device mounted in the open air. It is relatively easy to build a container for compressed gases and to mount a generator in it, and this, in fact, has been done by Doctor Barton at Princeton, originally with the collaboration of Doctor Van de Graaff.

By far the most intriguing possibilities of this generator are found in its vacuum embodiment, because a high vacuum is the best of all insulators since it offers no "windage" resistance to the motion of the belt, and since many of the applications of the high voltage will themselves be in vacuum discharge tubes which can be built right into the generating system.

Such a generator has been designed and built. It is still in the experimental stage but various complicating factors have one by one been overcome. Experience to date indicates that there is in sight no insurmountable obstacle to the construction of generators which may even reach considerably higher voltages than the generator at Round Hill.

In conclusion you will be interested to know, if you do not know this already, that two Van de Graaff generators have been built and operated in Washington under the direction of Dr. Merle A. Tuve

of the Department of Terrestrial Magnetism of the Carnegie Institution. One of these has been actually used for experiments on atomic disintegration and the other instrument, a larger one developing upwards of 2,000,000 volts, is awaiting a suitable housing now under construction, for its satisfactory operation. Dr. Tuve in Washington, Dr. Coolidge of the General Electric Company and Dr. Slack of the Westinghouse Company, all of whom have built and experimented with Van de Graaff generators subsequent to the demonstration of Van de Graaff's first air operated instrument in the summer of 1931, have been very helpful in reporting their experiences with the generators.

In conclusion it may fairly be said that this new type of generator as an electrical instrument, has already been highly successful and shows promise of very considerable further development. It remains to be seen whether the necessity which was the mother of this invention,—namely, the desire for high speed particles for the study of atomic nuclei,—will lead to important new knowledge of atomic structure with the aid of this device. Several good men are beginning work on the application of these voltages to nuclear disintegration, and it will not be long before some indications, at any rate, may be obtained as to the significance of the new developments in high voltage technique.

Whether or not the apparatus will be successful in opening up new fields of atomic investigation, it has already opened up the possibility for electrical investigations and possible practical applications of electricity in a new voltage range, and it will be surprising indeed if there are not some developments of scientific and practical significance which will eventually emerge from this new field of activity.

PHYSICS.—*Thin film lubrication of journal bearings.*[1] MAYO D. HERSEY, Research and Development Laboratories, Socony-Vacuum Corporation.

Some years ago[2] it was shown how the problems of lubrication might be simplified with the aid of dimensional reasoning. The treatment then given was restricted to thick film lubrication, assuming a uniform viscosity throughout the film, and assuming rigid or at least geometrically similar bearing surfaces, thereby excluding the

[1] Received April 27, 1933.
[2] This JOURNAL 4: 542–552. 1914.

combination of a very heavy load with a very low speed. Even under those limitations the results were found practically useful, and in present day notation are usually referred to as the ZN/P relations.

This paper undertakes to extend the investigation to some of the simpler conditions of thin film lubrication.

THE CONCEPT OF THIN FILM LUBRICATION

Thin film lubrication has been described as a state in which the friction depends on some other property or properties in addition to the ordinary viscosity of the lubricant as measured at atmospheric pressure.[3] The term is not synonymous with boundary lubrication, where the effective properties of the lubricant are different from its bulk properties. Boundary lubrication may be considered a particular case of thin film lubrication. In general, thin film lubrication may be visualized as a state in which the bearing surfaces have been made to approach so closely that they can no longer be treated as perfectly smooth, perfectly rigid, and separated only by a perfectly adhering fluid of uniform viscosity.

A general study of thin film lubrication must therefore contemplate such phenomena as (1) velocity components, pressure gradients, and geometrical irregularities not recognized in Reynolds' equations; (2) localized pinching and heating effects between tangentially moving high spots on the opposite rubbing surfaces, resulting in non-uniform viscosity; (3) elastic deformation and thermal expansion, causing geometrical changes in the bearing surfaces; (4) boundary lubrication; (5) wear, seizure, and progressive chemical reactions, so far as they may properly be classed under the head of lubrication.

Kingsbury[4] found no departure from the ordinary laws of bulk viscosity down to films as thin as one forty-thousandth of an inch and up to rates of shear as high as 261,000 radians per second. Bulkley[5] found no evidence of plastic adsorbed films greater than one-millionth of an inch in thickness. Thus it appears that in practical journal bearings, we should expect the transition from thick film to thin film lubrication to be brought about due to the roughness of the surfaces, before there is any significant departure from bulk properties.

FACTORS AFFECTING THE COEFFICIENT OF FRICTION

With items (2) to (5) ruled out, the coefficient of friction, f, would

[3] Amer. Mach. 70: 919, 921. 1929.
[4] Mech. Eng. 41: 537. 1919.
[5] Bur. Standards Journ. Research (RP 264) 6: 89–112. 1931.

be a function of the same variables entering into thick film lubrication. These variables are the absolute size of the bearing; its geometrical shape in every particular, including the clearance-diameter ratio, length-diameter ratio, and roughness; and the operating conditions, comprising the external load system, speed, and viscosity of lubricant. The load system may be specified by the load per unit of projected area together with the resultant couple, if any, taken about an axis perpendicular to the axis of rotation, such as might be caused by belt pull or misalignment. The viscosity of the lubricant may be specified by its value at atmospheric pressure and at the temperature of the bearing surface. It is assumed that the bearing is running in a practically steady state, with an unrestricted supply of homogeneous lubricant. For geometrically similar bearings the variables required by item (1) may therefore be catalogued as follows:

D, the journal diameter;
P, load per unit projected area;
M, moment of external couple;
N, speed in revolutions per unit time; and
Z, the viscosity of the lubricant.

The principal variables required by item (2) are the heat capacity per unit volume and thermal conductivity of the lubricant, together with its temperature and pressure coefficients of viscosity. The heat capacity determines the temperature rise in any particular volume element due to the heat generated by friction; the conductivity determines the temperature distribution; the temperature coefficient, in conjunction with other factors already mentioned, determines the decrease in viscosity due to local heating; and the pressure coefficient, with other factors, determines the increase in viscosity due to the relatively high local pressures that may be set up. To a first approximation it appears that the variables required by item (2) are:

a, the temperature coefficient of viscosity, or $(1/\mu)(d\mu/dt)$, in which μ is the viscosity at temperature t and pressure p;
b, the pressure coefficient of viscosity, or $(1/\mu)(d\mu/dp)$;
h, heat capacity of the lubricant per unit volume; and
k, conductivity of the lubricant.

Item (3) introduces phenomena governed by the elastic constants of the journal and bearing metals and their thermal expansivities. The elastic constants may be represented by Young's modulus and

Poisson's ratio. To a first approximation the latter may be considered constant, and the expansivities neglected because most of the expansion occurs between room temperature and the test temperature at which D, Z, etc., are measured. The principal variables called for by item (3) are therefore E_1 and E_2, Young's modulus for the journal and bearing respectively.

Although boundary lubrication, item (4), involves phenomena that are not yet understood, it would appear from the work of Hardy and others[6] that the coefficient of boundary friction may be assumed constant as a first approximation, provided (1) that the temperature variations are not too great, and (2) that sufficient time is allowed for the formation of the adsorbed layers. On this assumption the observed drop in friction with increasing speed under thin film conditions would be attributed to the coexistence of boundary lubrication with ordinary viscous action, the latter tending to separate the surfaces as the speed increases. For the purpose, then, of investigating thin film lubrication under conditions where boundary friction is a contributing but not the predominating factor, it may be tentatively assumed that the only additional variable called for by item (4) is the static coefficient, f_0.

Phenomena such as those described under item (5) which might permanently alter the identity of the bearing surfaces and of the lubricant, or involve appreciable expenditures of energy otherwise than in overcoming frictional resistance, are considered outside the scope of this investigation.

Collecting the variables listed above, it appears that the coefficient of friction under the conditions stated may be expressed by the qualitative relation

$$f = \text{funct}\,(D, P, M, N, Z, a, b, h, k, E_1, E_2, f_0); \qquad (1)$$

in which the requirement for geometrical similarity may be interpreted as applying only to the journal bearing in its unloaded state.

As there are still twelve independent variables left in spite of the severe narrowing down of the problem already undertaken, it is no great wonder that experimenters have found it difficult to obtain check results and to coordinate their observations in the field of thin film lubrication.

APPLICATION OF DIMENSIONAL THEORY

Four fundamental units are needed for measuring the thirteen quantities appearing in Eq. (1), as may be verified by inspection,

[6] Dictionary Appl. Physics, Macmillan, 1: 572–579. 1922. Proc. Roy. Soc. A. 138: 259–283. 1932.

since these involve thermal as well as kinetic quantities. Hence it follows from Buckingham's Π-theorem[7] that Eq. (1) is reducible to a relation connecting 13 − 4, or 9 dimensionless products. One of the products may be identified with the coefficient of friction itself, so that Eq. (1) becomes

$$f = \phi(X_1, \quad X_2, \cdots X_8), \tag{2}$$

in which ϕ is merely a symbol for some unknown function of the eight independent variables, or arguments, $X_1, X_2, \cdots X_8$.

The dimensions of the twelve quantities on the right of Eq. (1) are expressed in terms of force, length, time and temperature (F, L, T, θ) in Table 1, where colons have been used for convenience in place of the more conventional square brackets.

TABLE 1. DIMENSIONS ON THE F, L, T, θ SYSTEM

$D : L$	$Z : \frac{FT}{L^3}$	$k : \frac{F}{T\theta}$
$P : \frac{F}{L^2}$	$a : \frac{1}{\theta}$	$E_1 : \frac{F}{L^2}$
$M : FL$	$b : \frac{L^2}{F}$	$E_2 : \frac{F}{L^2}$
$N : \frac{1}{T}$	$h : \frac{F}{L^2\theta}$	$f_0 : 1$

One set of independent dimensionless products that may be constructed by reference to Table 1 is shown in Table 2. Other equivalent sets may be derived by interchanging quantities having the same dimensions. Eq. (2) may be expanded, if desired, by substituting directly into it from Table 2 or its equivalent.

This reduction in the number of independent variables from twelve to eight for thin film lubrication is less striking than the reduction from four to one obtained from the corresponding analysis of thick film lubrication.[8] Nevertheless, Eq. (2) in conjunction with Table 2 offers a definite guide for the planning and interpretation of experiments on thin film lubrication, an undertaking that would otherwise be even more complex than it now appears.

PROCEDURE FOR INCLUDING ADDITIONAL VARIABLES

If it is desired at any time to investigate the effect of additional quantities not included in Eq. (1) it will only be necessary to set up

[7] This JOURNAL 4: 347. 1914. Trans. Amer. Soc. Mech. Eng. 37: 263. 1915. Phil. Mag. 42: 696. 1921.

[8] This JOURNAL 4: 542–552. 1914.

TABLE 2. DIMENSIONLESS PRODUCTS FOR EQ. (2)

$X_1 = \frac{ZN}{P}$	$X_5 = \frac{k}{D^2PNa}$
$X_2 = \frac{M}{D^3P}$	$X_6 = \frac{E_1}{P}$
$X_3 = bP$	$X_7 = \frac{E_2}{E_1}$
$X_4 = \frac{h}{Pa}$	$X_8 = f_0$

by inspection the appropriate dimensionless product X corresponding to each new quantity introduced. Suppose, for example, any or all of the following quantities were to be included: (1) The latent period of Hardy, t_0, required for complete formation of the adsorbed layers under undisturbed conditions; (2) the density of the lubricant, ρ, as affecting its rate of escape from the space between tangentially approaching high spots, and its surface tension, S, as affecting its retention in the clearance space; (3) the second order coefficients of the viscosity-pressure-temperature surface, α, β, and γ, of which α denotes $\partial a/\partial t$, β denotes $\partial b/\partial p$, while γ denotes $\partial a/\partial p$ or its equal, $\partial b/\partial t$; (4) thermal expansivities, e_1, e_2, heat capacities, h_1, h_2, and conductivities, k_1, k_2, of the metals; (5) Poisson's ratio for the respective metals, σ_1, σ_2, and (6) the contact angles, A_1 and A_2, between

TABLE 3. ADDITIONAL DIMENSIONLESS PRODUCTS

Q	X	Q	X	Q	X
t_0	Nt_0	e_1	$\frac{e_1}{a}$	σ_1	σ_1
ρ	$\frac{\rho D^3N^2}{P}$	e_2	$\frac{e_2}{e_1}$	σ_2	σ_2
S	$\frac{S}{DP}$	h_1	$\frac{h_1}{h}$	A_1	A_1
α	$\frac{\alpha}{a^2}$	h_2	$\frac{h_2}{h_1}$	A_2	A_2
β	βP^2	k_1	$\frac{k_1}{k}$	.....	.....
γ	$\frac{\gamma P}{a}$	k_2	$\frac{k_2}{k_1}$	.....	.....

lubricant and metal. The new independent variable X corresponding to each new quantity Q is shown by Table 3. This procedure may be continued indefinitely.

While there is thus no difficulty in extending Eq. (2) to include as many variables as desired, it would seem to be of more immediate interest to examine the particular forms to which Eq. (2) may reduce when certain of the variables in Table 2 are held constant, or when the problem is sufficiently narrowed down to eliminate some of them.

DISCUSSION OF SPECIAL CASES

For properly loaded bearings $M=0$ so that X_2 of Table 2 disappears. Upon substituting into Eq. (2) we find for such bearings that

$$f=\phi_1\left(\frac{ZN}{P}, bP, \frac{H}{P}, \frac{K}{D^2PN}, \frac{E_1}{P}, \frac{E_2}{E_1}, f_0\right), \tag{3}$$

in which H has been written for h/a and K for k/a. That the three thermal properties a, h, and k should combine to form only two independent properties, H and K, is itself a noteworthy fact. It is also of interest that the absolute size, D, enters only one of the arguments of Eq. (3). This argument, X_5, appears to be a relatively unimportant one except for very low speeds; and if so, the equation assures us that the coefficient of friction will be relatively unaffected by changing the absolute size of the bearing, provided the corresponding bearing surfaces of different sizes are either practically smooth or similarly, not equally, rough. It is a familiar fact that the coefficient of friction is independent of size in thick film lubrication.

Limiting the analysis now to one particular bearing, $D=$const., $E_1=$const., and $E_2=$const.; so the argument X_7 disappears, while the remaining ones may be simplified. The factor P may as well be dropped from the first four arguments, since it now appears by itself in the fifth as an independent variable. Eq. (3) thus reduces to

$$f=\phi_2\left(ZN, P, b, H, \frac{K}{N}, f_0\right). \tag{4}$$

Eq. (4) is believed to be the most generally useful of any single equation in the paper. It suggests (1) that the viscosity of the lubricant, Z, can influence the coefficient of friction only through the product ZN; (2) that the conductivity of the lubricant affects the friction only through the ratio K/N; (3) that the results of experiments might be coordinated by plotting constant load curves ($P=$const.) with f

as ordinate against ZN as abscissa,[9] labelling each separate curve with the appropriate value of P, b, H, K/N, and f_0 so far as these can be determined.

The form of the variable K/N in Eq. (4) indicates that low conductivity has the same effect as high speed. This also is evident from any qualitative picture of the physics of thin film lubrication. If the lubricant were a perfect insulator, this variable would disappear, even at low speeds. In practice, the effect of K/N as well as the effect of f_0 may be expected to become negligible when the speed and viscosity are high enough. Eq. (4) then reduces to

$$f = \phi_3(ZN,\ P,\ b,\ H). \tag{5}$$

Under these conditions the pressure coefficient b and ratio of heat capacity per unit volume to the temperature coefficient of viscosity, H, would appear to be the two most significant properties of the lubricant, aside from its ordinary viscosity, Z.

APPLICATION OF HERTZ'S THEORY

For relatively smooth bearings where the general deformation, as distinguished from the deformation of the high spots alone, is considerable P may be replaced by P_0, the load per unit of effective contact area, or W/A_0 where W is the total load. Under these conditions X_6 and X_7 drop out since the effect of the elastic constants will be included in the factor A_0. From Hertz's theory[10] of cylinders in contact $A_0 \propto \sqrt{W}$, therefore $P_0 \propto \sqrt{W}$ and for one particular bearing, so that E_1, E_2, and D are constant, Eq. (3) may be written

$$f = \psi\left(\frac{ZN}{\sqrt{W}}, b\sqrt{W}, \frac{A}{\sqrt{W}}, \frac{K}{n\sqrt{W}}, f_0\right). \tag{6}$$

Possibly with smooth enough bearing surfaces, the effect of the arguments containing b, H, and K might be considered negligible to a first approximation. In this event Eq. (6) would reduce to the statement that for any one lubricant the coefficient of friction is a function of the single variable $ZN/\sqrt{W}$, a result that appears to be in accord with recent experimental data.[11]

FURTHER INVESTIGATION

In continuing this study it would seem desirable to consider (1) detailed calculation of possible magnitudes of the local pressures and

[9] For examples of charts in which f has been plotted against ZN see Zeit. V. d. I. 64: 449. 1920. Proc. A. P. I., Sect. III, p. 154. 1932.

[10] HERTZ, H. Journ. f. Math. (Crelle) 92. 1881. Ges. Werke, Leipzig, 1: 155. 1895.

[11] MCKEE, S. A. and MCKEE, T. R. Journ. S. A. E. 31: 371. 1932.

temperatures developed by the assumed tangential motion of rough spots; (2) tabulation of the pressure coefficient b and thermal constants H and K for available lubricants; (3) coordination of friction data in the light of the present results; (4) extension of the theory to gear lubrication; and (5) relation of thin film lubrication to the concept of oiliness.

PALEOBOTANY.—*The American white walnut or butternut,* Juglans cinerea *L., from the Upper Pliocene of Japan.*[1] SEIDO ENDO, Johns Hopkins University. (Communicated by E. W. BERRY.)

Description.—Nuts without outer soft part, ovoid-oblong in general outline, 4 to 6 cm. long, 2 to 3 cm. in maximum width and thickness, 4-ribbed, rough, deeply sculptured, and with about 4 sharp, longitudinal ridges, acuminated at apex, rounded at base; 2-celled at basal portion but 1-celled above in the inside, and about 4 mm. in thickness of the test.

Remarks.—The present materials are entirely identical in the outer ornamentation of the nut and inner features of the cell with the existing *Juglans cinerea* L., found in eastern North America. It now exists in New Brunswick and Ontario to North Dakota; south to Delaware; and in the Alleghanies to Georgia; and to Mississippi, Arkansas, and Kansas. It ascends to 2500 feet in Virginia.[2]

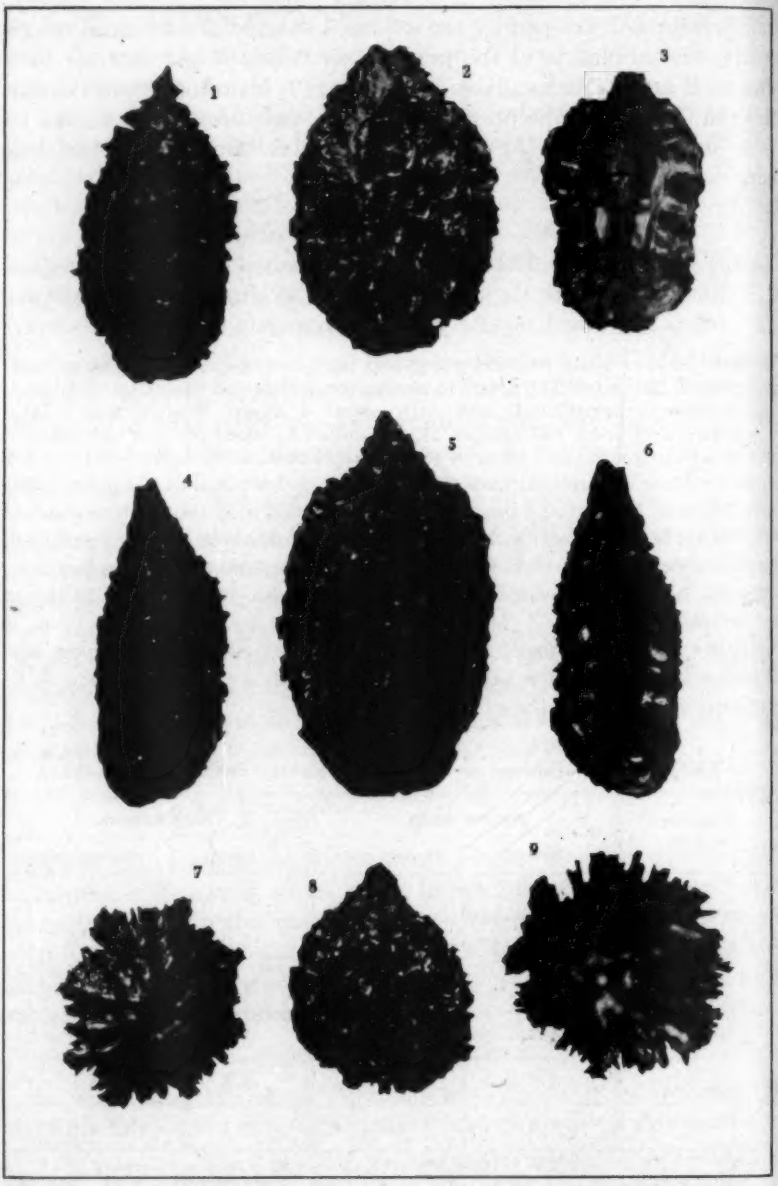
In the sizes of the fossil there are many variations. In this respect also it is closely allied to the existing species. Table 1 shows the comparison of the present materials and the existing species.

TABLE 1.—COMPARISON OF FOSSIL AND EXISTING SPECIES OF JUGLANS

NUMBER OF SPECIMEN	EXISTING SPECIES		FOSSIL MATERIALS	
	LENGTH	MAXIMUM WIDTH	LENGTH	MAXIMUM WIDTH
1	6.0 cm.	2.6 cm.	6.0 cm.	2.5 cm.
2	4.6	3.0	5.0	2.5
3	4.5	2.6	4.0	2.9
4	4.2	2.8	4.0	2.0
5	4.0	2.7	3.8	2.7
6	4.0	2.4	3.7	2.9

[1] Received January 24, 1933.

[2] BRITTON, N. L., and BOWEN, H. A. *An illustrated flora of the northern United States* 1: 579. 1913.



FIGS. 1–9. *Juglans cinerea* L.; 3, 6, The inner side; 7, 9, The basal portion. All slightly reduced.

These fossils were collected by F. Saito from Takagi, near Hanamaki-Machi, Iwate Prefecture, which is almost certainly Upper Pliocene in age, with many seeds (i.e. *Alnus*, *Prunus*, and *Styrax*, etc.).

Some years ago Hayasaka investigated other material from the same locality, without comparison with the existing material, and he described the species (in Japanese).[3]

Another occurrence from the Asiatic side is one on the River Aldan, which was described by Kryshtofovich.[4] This is quite similar to the present species and is almost certainly the same species.

From Europe this species was described by Engelhardt and Kinkelin from the Upper Pliocene of Klärbeckens and it is one of their most complete and beautiful specimens.[5] Ludwig described a species of *Juglans* (*J. gopperti* Ludwig) from the Pliocene lignite bed of Wetterau.[6] This is the nearest allied to our species. Another allied species is *Juglans tephrodes*, some of which[7] are quite similar to the present species.

Geological age.—As already stated, the present species was described by A. Kryshtofovich from eastern Siberia, a cleft of the Mammoth mountain on the left bank of the river Aldan, at a distance of about 45 versts from the mouth of the river Amga. He says:[8] "as to the age of the strata with *Juglans cinerea* L., if we follow Tschersky's conception, the appearance of these strata may be referred to the epoch of glacial phenomena in Europe, which is here indicated by the increasing moisture (and perhaps also by the softening of the climate?)."

This estimate of the age is somewhat doubtful because Tschersky's conception is also very doubtful.[9] With regard to another occurrence of *Juglans cinerea* from post-Pliocene of Europe[10] the writer has no

[3] HAYASAKA, I. *On the fossil butternuts from Hanamaki-Machi, Iwate Prefecture, Japan.* Journ. Geogr. Tokyi **38**: No. 444. 1926 (Japanese).

[4] KRYSHTOFOVICH, A. *The butternut from fresh-water deposits of the Province of Yakoutsk.* Mem. du Comité Geologique, N. S. **124**: 25–32. *Figs.* 3*a*, *b*, *c*, *d*; 4*a*, *b*, *c*; 5*a*, *b*, *c*; 6*a*, *b*, *c*; 7*a*, *b*, *c*; 8*a*, *b*, *c*, *d*. 1915.

[5] ENGELHARDT, H. and KINKELIN, F. *Oberpliocane Flora und Fauna des Untermaintales, insbesondere des Frankfurter Klärbeckens.* Sencken. Naturfor. Gesell. Abhandl. **29**: 236. *pl.* 30, *figs.* 3, 4*a*, *b*; 5*a*, *b*; 6*a*, *b*; 7*a*, *b*. 1911.

[6] LUDWIG, R. *Fossile Pflanzen aus der jüngsten Wetterauer Braunkohle.* Palaeont. **5**: 102. *pl.* 21, *figs.* 9, 9*a*, *b*, 10. 1857.

[7] UNGER, F. *Sylloge plantarum fossilium*, I. Denk. Kais. Akad. Wiss., **19**: 38. *pl.* 19, *figs.* 12–15. 1860.

[8] KRYSHTOFOVICH, A. Op. cit. p. 31.

[9] YABE, H. *On the climatic changes in Japan during the Pleistocene Epoch* (in Japanese). Reports Inst. Geol. and Pal., Tohoku Imp. Univ., Sendai, **3**: 1922.

[10] KRYSHTOFOVICH, A. Op. cit. p. 31; and ENGELHARDT, H., KINKELIN, F. Op. cit. p. 237.

accurate data[11] but in the deposits of Pliocene age there are many occurrences, as above mentioned.

It seems to the writer that the present species was widely distributed until upper Pliocene time, in the old world. It may, however, be almost absent from the deposits of Pleistocene age in most parts of the world except eastern North America.

The writer wishes to express his sincere thanks to Professor E. W. Berry for his valuable advice and assistance.

PALEOBOTANY.—*Fossil plants from Morrison, Colorado.*[1] EDWARD W. BERRY, Johns Hopkins University.

In the summer of 1916 the late Willis T. Lee collected a few very fragmentary fossil plants from the type section at Morrison, Colorado. These were the basis for a short paper[2] by the late Frank H. Knowlton published in March, 1920 in which these plants were compared with the Dakota sandstone flora and the following tentative identifications were listed:

Salix sp., cf. *Salix proteaefolia* Lesq.
Ficus daphnogenoides (Heer) Berry
Ficus magnoliaefolia Lesq. cf. *Eucalyptus dakotensis* Lesq.
Phyllites (2 species)

Preceding Knowlton's paper was one by Lee[3] advocating consideration of the Dakota as a group in this section, made up of the following 5 units:

1. Sandstone ("upper Dakota")
2. Sandy shale
3. Massive sandstone (Dakota of Lesquereux, "lower Dakota," Purgatoire)
4. Shaly sandstone (upper part of Morrison as originally described)
5. Conglomeratic sandstone ("Saurian conglomerate")

6, 7. Morrison formation

8, 9, 10. Sundance formation

This is sufficient, without a more extensive quotation, to render what follows intelligible.

The plants listed above on the authority of Knowlton came from member No. 4. I examined these after Knowlton's death and labelled them undeterminable. More recently I have looked them over again

[11] The occurrences of *Juglans cinerea* L. of Pleistocene age in Europe are very doubtful both as to the determinations and the geological age of the localities.

[1] Published with the permission of the Director of the U. S. Geological Survey. Received February 24, 1933.

[2] KNOWLTON, F. H. Amer. Jour. Sci. 49: 189–194. 1920.

[3] LEE, W. T. Amer. Jour. Sci. 49: 183–188. 1920.

more carefully. The collection consists of 16 pieces of a grayish gritty matrix with fragmentary carbonaceous impressions. The Survey Locality number is 7225 (Lee's No. 1262). Knowlton did not label any of the specimens but for most of them it is possible to pick out the ones to which the above names were meant to apply.

It will be noticed that but one of these was positively named. This was *Ficus magnoliaefolia*. The type of this species was described by Lesquereux[4] in 1883 from collections made by Lieutenant Beckwith at Morrison which, according to George L. Cannon as quoted by Lee, came from No. 3 of the section quoted above. Subsequently Lesquereux identified this species[5] from Ellsworth County, Kansas. These two are similar but not identical, although I am not prepared to say that they could not represent the same species. The single specimen in the Lee collection has an outline more like the Kansas leaf than it is like the type, but again there are slight differences especially in the fewer secondaries in the Lee specimen. The material is too poor for a positive determination and I would certainly hesitate to vouch for its correctness. The other species supposed to be represented are still more vague and fragmentary and I do not regard any of them as entitled to any weight in arriving at the age of the horizon.

Accompanying the collection from Loc. 7225 are 5 specimens in a brownish gritty sandstone with brownish impressions of fragmentary leaves collected by Lee from a horizon 25 ft. above the base of No. 3 (Purgatoire). These bear the Survey Locality No. 7224 (Lee's No. 1267). None of these are accompanied by identifications and I certainly regard them as undeterminable, although they have a Dakota aspect.

A single additional specimen bearing Locality No. 7225 is a loose piece sent in by Lee. The covering note states "It seems to come from the Morrison but might easily be the Dakota." The lithology and character of the leaf impressions are that of Loc. 7224 and not that of 7225.

One face has a perfectly recognizable leaf of *Aralia wellingtoniana* Lesq. and the other face the greater part of a lanceolate leaf of *Ficus daphnogenoides* (Heer) Berry. The first is a Dakota, Raritan, Woodbine species and the second occurs in all of these formations and in the Magothy and Tuscaloosa in addition.

In the summer of 1921 Dr. Stanton visited the Morrison region and made a collection of plants from a shaly lens near the middle of No. 3

[4] LESQUEREUX, L. Cret. and Tert. Fl., p. 47. *Pl.* 17, *figs.* 5, 6. 1883.
[5] LESQUEREUX, L. Dakota Flora, p. 79. *Pl.* 16, *fig.* 4. 1892.

of Lee's section (quoted above). The exact locality is north of Bear Creek at Morrison on the west slope of the Dakota hogback and the specimens bear the Survey Locality No. 7501 (Stanton's No. 1892). Dr. Stanton informs me that this shaly lens is about 50 feet above a plant-bearing bed which in his opinion is the horizon from which came Lee's collection, that is, "4. Shaly sandstone (upper part of Morrison as originally described)" and the basis of Knowlton's published paper. The Stanton collection is also of very scrappy material but it contains one specimen that can be positively determined and which

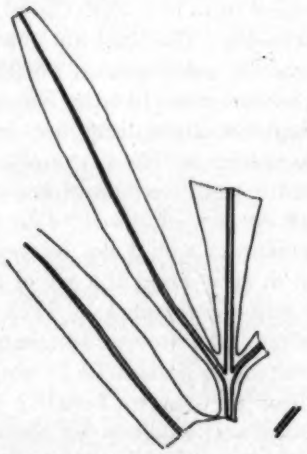


Fig. 1. *Sapindopsis* from Morrison, Colorado.

is figured herewith and undoubtedly is *Sapindopsis variabilis* Fontaine.

The genus *Sapindopsis* was proposed by Fontaine[6] in 1890. Some years later the writer[7] redefined it and pointed out its nearest living relatives among American genera of the Sapindaceae. Three species were recognized and these came from the Patapsco formation of Maryland and Virginia, and there is satisfactory evidence for assigning the Patapsco formation to the Albian stage of the European time scale, i.e. near the top of the Lower Cretaceous.

In more recent years one or the other of the three original species have been found in a number of other regions, all North American

[6] FONTAINE, W. M. Mon. U. S. Geol. Survey 15: 296. 1890.
[7] BERRY, E. W. Md. Geol. Survey, Lower Cretaceous, p. 467. 1911.

however, and a fourth and better characterized species has been added from the Cheyenne sandstone of southern Kansas.[8]

The Patapsco species *Sapindopsis variabilis* was the most common species in that formation, and as its name indicates, it shows considerable variability and appears to grade into what was called *Sapindopsis magnifolia*. In all these species the thick lanceolate detached leaflets are easily confused with the lanceolate leaves or leaflets of other and unrelated genera and at one time or another one or the other have been referred to *Eucalyptus*, *Ficus*, *Aralia*, and *Rhus*. This is particularly true where the specimens are entombed in sandstones and were more or less macerated before burial, as in the so-called Fuson formation of the Black Hills. The present specimen is unmistakably a part of a leaf of *Sapindopsis variabilis* showing parts of five rather narrow leaflets and is particularly good and characteristic of the three distal leaflets. These are rather narrower than usual but not narrower than many I have seen. Their coalescent bases and winged rachis are unmistakable, and could not possibly be confused with any other Cretaceous plant. They show no venation other than midveins, and failure to note that they were leaflets and not lanceolate leaves would readily lead one to compare them with *Salix* or *Eucalyptus*. Both what has been called *Salix proteaefolia* as conceived by Lesquereux and not by Newberry, and *Eucalyptus dakotensis*, both tentatively identified by Knowlton from No. 4 of the section at Morrison, might be and probably are only the leaflets of *Sapindopsis variabilis*. This indicates that the two plant-bearing beds at Morrison—one in No. 3 of Lee's section and the other in the upper part of No. 4 of the same section—contain essentially the same flora and presumably belong to the same formation.

Sapindus variabilis is exceedingly common at many localities in the Patapsco formation of Maryland and Virginia and is by far the most characteristic species of that formation. It was identified by Ward from the supposed Fuson formation of the Black Hills at Oak Creek, Wyoming, and is common in the Cheyenne sandstone near Belvidere, Kansas. Cockerell[9] suggested this species for some undetermined material from an unknown geologic horizon in southwestern Colorado, photographs of which material I have examined and consider very inconclusive.

The certain presence of *Sapindopsis* in the section at Morrison casts considerable additional doubt upon Lee and Knowlton's as-

[8] BERRY, E. W. U. S. Geol. Survey Prof. Paper 129: 216. *Pls.* 49–54. 1922.
[9] COCKERELL, T. D. A. This JOURNAL 63: 110. 1916.

signment of one of the plant-bearing beds to the Morrison formation, but the question as to whether the age is late Lower or early Upper Cretaceous remains as uncertain as before, and is complicated by the fact that the so-called Dakota flora of the Denver Basin came from beds now referred to the Purgatoire formation and not from what I would call the true Dakota in the restricted sense as the littoral deposits of the Benton sea and the synchronous continental deposits of the time represented by that transgression.

It is probably true that what has been called Purgatoire is to be correlated with the Mentor formation and Cheyenne sandstone of Kansas, but so far as the range of *Sapindopsis* is evidence its horizon could equally fit into the top of the Lower or the base of the Upper Cretaceous. It certainly does not seem to me to afford any direct evidence regarding the age of the Dinosaur-bearing Morrison, although I would be inclined to regard it as circumstantial evidence of the Lower Cretaceous rather than the Jurassic age of the Dinosaur-bearing Morrison.

ZOOLOGY.—*Notes on shrimps of the genus* Macrobrachium *found in the United States.*[1] WALDO L. SCHMITT, U. S. National Museum.

From time to time specimens of the larger freshwater shrimps of the genus *Macrobrachium* have been received at the United States National Museum for identification. Information yielded by some of these sendings is of such interest that publication seems desirable.

Macrobrachium acanthurus (Wiegmann), though long known to range from the Rio Grande River in Texas to Rio Grande do Sul, Brazil; Panama, and Ecuador,[2] is here for the first time recorded east of Texas. On January 11, 1922, a specimen was taken, it was said, from "brackish water" near Lockport, Louisiana, and sent to the United States Bureau of Fisheries by Mr. E. A. Tulian, then Superintendent of the Fisheries Division of the Louisiana Department of Conservation. Not only did this specimen extend the range of the species eastward across the whole of the state of Texas, but it also proved to be the largest *M. acanthurus* ever seen at the Museum. The specimen measures from the tip of the rostrum to the extremity of the telson all of 170 mm.; the large chela is about 74 mm. long.

This species must be of comparatively rare occurrence in the state, for when asked about the matter, Mr. Tulian replied that "so far

[1] Received February 15, 1933.

[2] RATHBUN, M. J. Proc. U. S. Nat. Mus. 38: 604. 1910. We also have specimens in the National Museum extending the range of *M. acanthurus* northward along the west coast of North America to Mazatlan, Mexico.

as we are aware, only four of such shrimp have been taken from our waters." No further specimens have ever come to the attention of the Museum, though the State fisheries representatives were, at that time instructed to be on the watch for them. Five years later, August 29 1927, the first *M. acanthurus* was found in Mississippi, at Ocean Springs, where Captain Ellis Handy captured two specimens in a partly sunken boat. One of these was forwarded to the National Museum for determination, through the interest of Dr. R. W. Harned, then of the State Plant Board of Mississippi. Captain Handy never before had encountered this form, nor has it since come to our notice from this state. In a quite recent check-up, I wrote Captain Handy. He replied, "The specimen sent in was discovered by accident as a sunken barge was raised in Fort Bayou. As the water was bailed out I found two small and one large shrimp and the peculiarity of it made me send the larger one in for identification. At the time no local man could tell me anything of it. I have made the rounds of the local fishermen, particularly those who use troll boats and seines. Three or four men stated that they had almost every season found two or three similar shrimp in their catch."

The very next year, however, we were apprised of the presence of *M. acanthurus* in Florida. In August, 1928, Mr. Robert Ranson, of St. Augustine, shipped us two lots, thirty-seven specimens in all, that had been taken from the large central pool of the patio of the Alcazar Hotel, a very considerable eastward extension of the range of the species.

No less remarkable is the fact that in company with these specimens from Florida were found a *Macrobrachium jamaicense* (Herbst), and two specimens of *M. olfersii* (Wiegmann). With these were three other incomplete specimens; one has been tentatively referred to *M. jamaicense*, and the other two to *M. olfersii*.

Naturally, the question was raised as to how these shrimp could have gotten into this enclosed pool. At first it was suspected that they might have been unwittingly introduced with the tropical fish with which the pool had been stocked. Mr. Ranson looked into this phase of the matter, and a month later wrote that the *Macrobrachium* had been noted for some years in these pools, but the sword-tails had been introduced only the previous year from South America. He was convinced that the shrimps had entered the pool by means of the overflow drain leading to a stream outside. If there are any doubts regarding the streams outside as the source of the *M. acanthurus* found in the Alcazar pool, it would seem that additional records of the

occurrence of the species in Florida would set them at rest. Two such finds did come to us less than two years later. In the summer of 1930 Captain John Mills, of the yacht "Anton Dohrn" of the Tortugas Marine Laboratory of the Carnegie Institution, gave me two specimens from the Miami River, which had been caught under a set of ways on which one of the laboratory launches had been hauled out for repairs. He tells me (Sept., 1932) that there used to be quite a lot of them in the river, and that as soon as the present dredging operations which have made the water too muddy to look for shrimp have been completed, he will get me additional specimens. The same year, Mr. Edward J. Brown, sent us a specimen from Coconut Grove, Florida.

Macrobrachium jamaicense (Herbst) has perhaps a wider range than the preceding form, having heretofore been found in the "fresh waters of the Pacific slope of North America from Lower California to Peru, and the Atlantic slope, from Texas to Brazil, including the West Indies."[3] Now, by means of Mr. Ranson's Alcazar pool collections, we are enabled to establish a first record within the continental United States other than from the state of Texas, and a second from Silver Springs, Marion County, in the same state, where Mr. E. Ross Allen has speared several from as much as thirty feet or more of water. Two of these Silver Springs specimens have come into the possession of the National Museum through the kind offices of Dr. T. Van Hyning of the Florida State Museum at Gainesville. Though the larger is of good size, measuring from tip of rostrum to the extremity of the telson 202 mm., with a larger chela of about 92 mm., Dr. Van Hyning wrote at the time that "we still have one other specimen about twice the size of the present one, and in some ways in better condition, which we are saving for the exhibition series."

Mr. Allen told me that the largest specimen he ever took in Silver Springs was twenty-two inches (nearly 559 mm.) long, measured from the end of the telson to the extremity of anteriorly extended claws. This exceeds by about two inches the largest specimen in the National collections which was taken in Devil's River, Texas, by Mr. John Roth, the donor, in 1910. Weighing three pounds, it measures from tip of rostrum to extremity of telson a shade over 266 mm.; larger right chela, movable finger, and palm taken together, 188 mm. Following a personal visit to Washington this past summer, Mr. Allen kindly donated to the National Museum a very large specimen, but yet intermediate in size between the two just mentioned, together with two chelipeds of another specimen or two. The larger of these legs has

[3] RATHBUN, M. J. loc. cit.

a chela or claw about seven and five-eighths inches (about 193 mm.) in length and also a little larger than the larger cheliped of our Devils River specimen.

Macrobrachium olfersii (Wiegmann) has been found to range from La Paz, Lower California, to the Rio Sabana, Panama, and from Vera Cruz, Mexico, to Rio de Janeiro, Brazil, including also the West Indies.[4] A rather unexpected record for the continental United States is the one established by Mr. Ranson (mentioned above) for the Alcazar Hotel pool, St. Augustine, Florida. These particular specimens are of fair size, 78 and 81 mm. long, with larger chela of each about 43 mm. long and about 12 and 13 mm. wide respectively. The largest of this species in the National Museum, by the way, was received over thirty years ago. It comes from La Situ, Guadeloupe, and from tip of rostrum to extremity of telson measures 90 mm. long, large chela about 50 mm. long by 14 mm. wide, exclusive of spines.

Macrobrachium ohionis (Smith), according to the last published statement regarding its distribution, "is found in the Mississippi and lower Ohio Rivers (up to Cannelton, Ind.)"[5] The specimens of this species preserved at Washington are mostly from the state of Louisiana, and these chiefly from the lower Mississippi in the general vicinity of New Orleans and Lake Pontchartrain; with several from Lake Lapourde, Morgan City, and Calcasieu Pass. Texas is represented by a number of specimens from the Trinity and Lavaca Rivers, and a few from Big White Oak Bayou, two miles south of Houston. On the other hand, we possess but a single record from the state of Mississippi, a lone individual from Baldwin Lodge, near the Gulf Coast, and not far from the Louisiana-Mississippi state line; perhaps to be considered as being in the general region of New Orleans.

It was, therefore, of considerable interest that two shrimp sent in for determination from Savannah, Georgia, in 1929, by Mr. Ivan R. Tomkins, of the U. S. Dredge "Morgan," should prove to be *M. ohionis*. They were found just above the city of Savannah in fresh water. In May, 1930, he sent two more specimens of *M. ohionis*, both ovigerous, from the entrance of the Altamaha River, Georgia; and just this last June he sent more specimens that were found together at the foot of East Broad Street (Savannah) in 2-10 feet of water with the notation that "the water was quite fresh at that stage of the tide."

It was even more surprising to learn, in checking over the Museum's

[4] RATHBUN, M. J. loc. cit.
[5] ORTMANN, A. E. in WARD and WHIPPLE, Freshwater Biology, p. 845. 1918.

files, that a good many years ago another specimen of this very species from our southeastern coast had been identified, but never published, by Dr. Mary J. Rathbun. This happens to be the largest specimen of the species in our collection, and perhaps the largest known. It was collected by Mr. J. W. Milner in 1878 at Avoca, North Carolina. From the tip of the rostrum to the extremity of the telson it is just about 102 mm. long. The chelae are lacking from the large, second, pair of legs.

Were it not for this early find of Mr. Milner's, one would have been tempted to believe that these usually more tropical Mexican and Central and South American shrimps, and our own *Macrobrachium ohionis* of the Mississippi water-shed and westward were gradually making their way eastward along the Gulf coast, and northward along the east coast of the United States.

From what has been here brought together, it would seem that at least the larger bodies of fresh water of our southern, and central states, especially rivers which might harbor the larger shrimps, *Macrobrachium*, have received altogether too little attention from biologists. For example, Forbes, back in 1876, recorded[6] "*Palaemon ohionis* Smith abundant at Cairo, where it is frequently eaten. Smaller specimens were taken in the Mississippi near Grand Tower, in Jackson county, and it is reported by boatmen to occur from St. Louis to New Orleans, growing larger towards the south. It has not yet been found in the Illinois River."

Is *M. ohionis* confined to the Mississippi below St. Louis and the lower Ohio to the exclusion of the other larger tributaries of these rivers? Whether or not, certainly an interesting ecological and distributional problem is here awaiting study; likewise, with the other North American species of *Macrobrachium*.

Except for friends of the Museum and certain amateur naturalists much interested in the world about them, these extensions of range would have gone undiscovered. Further observations or notes on these and any other fresh water shrimps found in the United States as well as specimens will be greatly appreciated.

While this note was yet in proof I received from Captain Mills another large freshwater shrimp which he caught in a boat slip at Fogel's shipyard close by the railway bridge crossing the Miami River, in Miami, May 17, 1933. It is an old *M. jamaicense*, 236 mm. long from end of telson to the tip of rostrum, which appears not to have moulted for some time as it is much overgrown with serpulid tubes. The larger left chela, fingers and palm to-

[6] FORBES. *List of Illinois Crustacea*. Ill. Mus. Nat. Hist. Bull. 1: 5. 1876.

gether, is approximately 200 mm. long. Compared with the exceptionally large Silver Springs specimen above, it is about 5-3/4 inches shorter, measured as Mr. Allen did his, from the hinder margin of the telson to the ends of the fingers of the extended chelipeds.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

THE ACADEMY

251ST MEETING

The 251st meeting of the Academy was held in the Auditorium of the Interior Department Building on Thursday, January 12, 1933. About 240 persons were present. Doctor MARIUS BARBEAU, Ethnologist, National Museum of Canada, delivered an address illustrated with motion pictures and lantern slides on *French Canada: its survival.*

At the close of the address the President declared a recess for a few minutes.

The 35th annual meeting of the ACADEMY was called to order at 9:45 by President ADAMS; 31 members were present.

The report of the Corresponding Secretary, PAUL E. HOWE, showed the following items of general interest:

Membership: During the year 1932, 29 persons were elected to regular membership. Of those elected, 27 had accepted and qualified for membership before the end of the year and 2 had declined membership. Doctor CHARLES E. MUNROE, Forest Glen, Maryland, was elected to honorary membership in recognition of his eminence as a chemist, educator, and explosives engineer. Thirty-one resignations were accepted, of which twelve were resident and 19 non-resident members. The ACADEMY lost by death 22. The net loss in membership was therefore 26 or 4.6 per cent.

By request of the President the ACADEMY stood while the Secretary read the following list of deaths reported during the year:

LOUIS W. AUSTIN	C. F. LANGWORTHY
S. I. BAILEY	C. DWIGHT MARSH
OUTRAM BANGS	WILLIAM J. HOLLAND
LOUIS A. BAUER	ERNEST HOWE
A. C. GILL	W. B. PARSONS
GEORGE K. BURGESS	IRWIN G. PRIEST
N. A. COBB	C. W. RICHMOND
G. L. COYLE	W. A. SLATER
B. K. EMERSON	F. W. STEVENS
B. W. EVERMANN	W. S. THAYER
R. L. FARIS	C. P. TOWNSEND

On January 1, 1933, the membership consisted of 15 honorary members, 3 patrons, and 543 members, one of whom was a life member. The total membership was 561 members, of whom 388 reside in or near the District of Columbia, 147 in other parts of the continental United States, and 26 in foreign countries.

The Recording Secretary reported that the 35th year of the ACADEMY began with the 246th meeting and ended with the 251st meeting. Two of the six meetings were joint meetings—the 249th with the Geological Society and the 250th with the Philosophical Society. The minutes of these meetings are published in the Journal.

The Treasurer reported that the receipts of the ACADEMY during the past year amounted to $7457.29 including return of investments of $2050.00 and interest on investments of $1293.03. The disbursements amounted to $7749.14 including an investment of $2062.50. The bank balance at the end of the year was $1576.84. The investments of the ACADEMY comprise $6337.50 in stocks, $6808.87 in bonds and $8000.00 in real estate notes making a total of $21,146.37 computed on the basis of cost to the ACADEMY. The assets of the ACADEMY were estimated as $22,913.03.

The report of the Auditors approving the Treasurer's accounts was received and filed.

Upon motion of Doctor GRIGGS, thanks of the ACADEMY were extended to the Treasurer for the wisdom with which he had protected the investments of the ACADEMY.

The report of the Board of Editors was presented by the Senior Editor, HUGH L. DRYDEN. The report stated that volume 22 consisted of 572 pages and 79 original papers and was illustrated by 23 halftones and 61 line cuts. The total cost per page, exclusive of reprints, was $6.62. The cost to the ACADEMY of supplying 50 free reprints was approximately $0.60 per page. The report described the changes of policy authorized by the Board of Managers as a result of the work of the special Journal Committee, namely, the change to monthly publication, the contract with Science Service to provide news notes, the new printing contract, and the attempt to provide one article of general interest in each issue. Upon motion of L. B. TUCKERMAN, a vote of thanks was extended to the Board of Editors for the efficient handling of the Journal during the past year.

Doctor L. A. ROGERS, Chairman of the Board of Tellers, reported 164 ballots counted with the election of the following officers: *President*, ROBERT F. GRIGGS; *Non-resident Vice-Presidents*, F. A. VENING-MEINESZ and EDWARD A. BIRGE; *Corresponding Secretary*, PAUL E. HOWE; *Recording Secretary*, CHARLES THOM; *Treasurer*, H. G. AVERS; *Managers for the term of three years ending January, 1936*, M. C. HALL and S. A. ROHWER.

The list of Vice-Presidents nominated by affiliated societies was read by the Recording Secretary as follows:

Anthropological Society,	N. M. JUDD
Archaeological Society,	J. TOWNSEND RUSSELL
Bacteriological Society,	N. R. SMITH
Biological Society,	H. H. T. JACKSON
Botanical Society,	C. L. SHEAR
Chemical Society,	E. WICHERS
Columbia Historical Society,	ALLEN C. CLARK
Electrical Society,	E. C. CRITTENDEN
Entomological Society,	HAROLD MORRISON
Geological Society,	F. E. MATTHES
Helminthological Society,	G. STEINER
Medical Society,	H. C. MACATEE
National Geographic,	F. V. COVILLE
Mechanical Engineers,	O. P. HOOD
Military Engineers,	C. H. BIRDSEYE
Philosophical Society,	H. L. CURTIS
Society of Foresters,	F. C. CRAIGHEAD
Washington Engineers,	N. H. HECK

By vote of the ACADEMY the Secretary was directed to cast one ballot for the list as read and the Vice-Presidents were declared elected. The Chairman of the Board of Tellers, L. A. ROGERS, reported the approval of the affiliation of the Washington Section of the Institute of Radio Engineers.

The senior Vice-President, H. L. CURTIS was appointed to escort President ROBERT F. GRIGGS to the chair. The new President addressed the Academy briefly. He appointed H. L. DRYDEN, senior editor, and Vice-President STEINER as members of the executive committee, and JOHN A. STEVENSON to the Board of Editors. He declared the meeting adjourned at 10:23.

252ND MEETING

The 252d meeting of the ACADEMY was held in the Assembly Hall of the Cosmos Club on Thursday, February 16, 1933. About 125 persons were present. President R. F. GRIGGS introduced Doctor L. H. ADAMS, retiring President of the ACADEMY, who delivered an address on *The basic concept of the physical sciences.*

CHARLES THOM, *Recording Secretary.*

ANTHROPOLOGICAL SOCIETY

The Anthropological Society of Washington at its annual meeting held on January 17, 1933, elected the following officers for the ensuing year: *President,* J. N. B. HEWITT; *Vice-president,* MATTHEW W. STIRLING; *Secretary,* FRANK H. H. ROBERTS JR.; *Treasurer,* HENRY B. COLLINS JR.; *Vice-President of the Washington Academy of Sciences,* N. M. JUDD; *Members of the Board of Managers,* BIREN BONNERJEA, GEORGE S. DUNCAN, HERBERT W. KRIEGER, FRANK M. SETZLER, WILLIAM DUNCAN STRONG.

The following is a report of the membership and activities of the Society since the annual meeting held on January 19, 1932.

Membership:	
Life members	3
Active members	52
Associate members	6
Honorary members	22
Corresponding members	22
Total	105
Deceased:	
Active members	2
Life members	1
Honorary members	1
Total	4
Resigned:	
Active members	4
Associate members	1
New Members:	
Active	3
Transferred:	
Active to Associate	1

The Society lost through death the following members: Dr. DANIEL FOLKMAR, past secretary, July 21, 1932; and Dr. FRANCIS LAFLESCHE, past president, September 5, 1932; active members. Baron ERLAND NORDENSKIÖLD, July 1932, honorary member. Mrs. F. WILSON POPENOE, December 30, 1932, life member.

Members resigning at the close of the year were: H. S. BERNTON, W. H. JACKSON, HENRY C. MACATEE, and R. H. REICHELDERFER, from the active list; and F. WILSON POPENOE from the associate group.

Members elected during the year were: ERIK K. REED, FRANK M. SETZLER, and LOREN L. WEDLOCK.

Mr. MARCUS GOLDSTEIN transferred his membership from active to associate.

The financial statement (Treasurer's report) is as follows:

Funds invested in Perpetual Building Association	$1034.15
21 Shares Washington Sanitary Improvement Co., par value $10 per share	210.00
2 Shares Washington Sanitary Housing Co., par value $100 per share	200.00
Cash in bank	201.84
Total	$1645.99
Bills outstanding	None

Papers presented before regular meetings of the Society were as follows:

January 19, 1932. 636th regular meeting. *The Indians of the Northern Plains*, by Dr. ROBERT H. LOWIE, professor in anthropology, University of California.

February 25, 1932. 637th regular meeting. *The archeology of the Southwest, from the basket makers to the pueblos*, by N. M. JUDD, curator of archeology, U. S. National Museum. *The ethnology of the pueblo peoples in contrast to the other peoples of the Southwest*, by Dr. WM. DUNCAN STRONG, ethnologist, Bureau of American Ethnology. By vote of the Board of Managers this meeting was changed from the regular date, February 23 to the 25th.

March 15, 1932. 638th regular meeting. *Recent excavations in France and Czechoslovakia*, by J. TOWNSEND RUSSELL JR., honorary collaborator in Old World Archeology, U. S. National Museum.

April 19, 1932. 639th regular meeting. *World history as a cultural tug of war*, by Dr. JOHN M. COOPER, Catholic University of America. This was the retiring presidential address.

October 18, 1932. 640th regular meeting. *The Jivaro Indians of eastern Ecuador*, by MATTHEW W. STIRLING, chief, Bureau of American Ethnology.

November 15, 1932. 641st regular meeting. *In the Brazilian wilderness, an account of the Matto Grosso expedition to Brazil*, by VINCENZO M. PETRULLO, University of Pennsylvania Museum.

December 20, 1932. 642d regular meeting. *Bush Negroes and Choco Indians of northwest Colombia*, by W. A. ARCHER.

Papers presented before special meetings of the Society were as follows:

January 5, 1932. *Indians of the Great Basin*, by Dr. ROBERT H. LOWIE, professor in anthropology, University of California.

February 11, 1932. *The Indians of California*, by Dr. A. L. KROEBER, professor in anthropology, University of California.

A special joint meeting with the American Association of Physical Anthropologists was held on March 22, 1932, in the auditorium of the U. S. National Museum. DR. CARL VON HOFFMAN spoke on the subject, *The wild tribes of Formosa*.

The special meetings of January 5 and February 11, and the regular meetings of January 19 and February 25 were held in the auditorium of the U. S. National Museum. The remaining regular meetings were held in Room 42-32 of the museum building.

The meetings of January 5, January 19, February 11, and February 25, together with that held on December 15, 1931, formed a special series of five lectures relating to the Indian Tribes of western North America.

FRANK H. H. ROBERTS JR., *Secretary*

SCIENTIFIC NOTES AND NEWS

Prepared by Science Service

NOTES

National Academy of Sciences.—The National Academy of Sciences held its regular spring meeting in Washington on April 24, 25 and 26, with sixty-three papers on its program, nine of which were by Washingtonians or by scientists affiliated with Washington institutions. The principal evening lecture was by Dr. THOMAS HUNT MORGAN of the California Institute of Technology, on *The bearing of genetics on the theory of evolution.*

The Academy dinner, on the evening of Tuesday, April 25, was addressed by Dr. W. W. CAMPBELL, President of the Academy, who called particular attention to the condition of stress and anxiety in many research institutions, due to the curtailment or threatened curtailment of necessary support. He urged that the scientific work of the federal government in Washington should be preserved and continued because the scientific bureaus of the government undertake work of great benefit to the nation which cannot be done by universities or other research institutions.

Medals awarded by the Academy were: the Alexander Agassiz Medal to Dr. ALBERT DEFANT of the Institut für Meereskunde, Berlin; the Public Welfare Medal to Dr. WILLIAM H. PARK of New York City; the John J. Carty Medal and Award, a newly established honor of the Academy, posthumously to Dr. JOHN J. CARTY; the Henry Draper Medal to Dr. V. M. SLIPHER, Lowell Observatory, Flagstaff, Ariz.; and the Mary Clark Thompson Medal to Dr. FRANCIS ARTHUR BATHER, of Wimbledon, England. Fourteen persons were elected to membership in the Academy.

An outstanding event of the Academy meeting was the demonstration concert by the Philadelphia Symphony Orchestra, on the evening of Thursday, April 26, at Constitution Hall. It was played in Philadelphia, transmitted to Washington by three special telephone circuits, and reproduced on the stage by three loudspeakers, with Director LEOPOLD STOKOWSKY at the controls. In addition to the rendition of a full concert, with volume and tonal effects quite beyond the reach of an orchestra as ordinarily conducted, the audience was treated to an explanatory lecture by Dr. HARVEY FLETCHER, of the Bell Telephone Laboratories, who also demonstrated some of the mechanics of the extraordinary sound control made possible by the method.

American Philosophical Society.—Several Washington scientists presented papers at the meeting of the American Philosophical Society, which met at Philadelphia on April 20, 21 and 22. Dr. ALES HRDLICKA of the U. S. National Museum spoke on *The forehead: its esthetic and anthropological values.* The subject of MATTHEW W. STIRLING, Chief of the Bureau of Ethnology, Smithsonian Institution, was *Jivaro Shamanism.* Dr. ELMER A. HARRINGTON of the U. S. Bureau of Standards presented a report on *Further experiments on the continual generation of heat in certain silicates.* Three members of the staff of the Carnegie Institution of Washington also read papers. They were:

Dr. ALFRED V. KIDDER, on *Mayan explorations and their results;* Dr. FRANCIS G. BENEDICT, on *Human gaseous metabolism in atmospheres of pure oxygen;* and Dr. OSCAR RIDDLE, on *Differentiating some functions of anterior pituitary hormones.*

American Geophysical Union.—The fourteenth annual meeting of the American Geophysical Union was held at the building of the National Academy of Sciences, on April 27, 28 and 29. Jointly with the Union, the Eastern Section of the Seismological Society of America also held its meeting, part of the sessions taking place at Georgetown University. A full program of papers was presented. During the meeting, on Friday noon, April 28, Rev. JAMES B. MACELWANE, S.J., of St. Louis University, broadcast a radio talk on *Earthquakes, what are they?* over the nationwide network of the Columbia Broadcasting System, under the auspices of Science Service.

American Meteorological Society.—The American Meteorological Society met on the morning of Saturday, April 29, at the U. S. Weather Bureau. An outstanding feature of its program was a paper by Prof. LARS VEGARD, professor of physics at the Kongelige Frederiks University, Oslo, on *The aurorae and the high strata of the atmosphere.* Prof. Vegard also presented papers before the National Academy of Sciences and the American Geophysical Union.

Other Scientific Meetings.—During late April and early May Washington was host to the Acoustical Society of America, the American Physical Society, the Horological Institute of America, the Catholic Anthropological Conference, and a group of seventeen medical, surgical and psychiatric societies.

Sigma Xi.—The annual dinner and meeting of the Washington chapter of the Society of Sigma Xi was held at the University Club on the evening of Tuesday, May 9. Dr. ALEXANDER T. WETMORE of the U. S. National Museum was elected president for the ensuing two-year period. The meeting was addressed by Dr. PAUL R. BARTSCH of the U. S. National Museum. Dr. Bartsch also spoke before the Sigma Xi Club of George Washington University on the evening of Monday, May 15.

At Georgetown University School of Medicine.—Dr. O. S. GIBBS, Professor of Physiology at the School of Medicine, University of Georgia, has been appointed Professor of Physiology and Chairman of the Department of Physiology. Dr. Gibbs has recently carried out very interesting researches on the nature of autonomic hormones. He has shown that certain drugs and chemicals are able to inhibit the enzyme which normally destroys the parasympathetic substance, acetyl-cholin, in the blood. Thus if eserin, for example, is injected into the blood stream and then the parasympathetic nerve to the salivary glands is stimulated one obtains not only increased salivation but also inhibition of the heart. (Because the acetyl-cholin is now not destroyed by the blood for the destructive enzyme is neutralized by eserin.)

Dr. WALLACE M. YATER, Professor of Medicine, discovered the first known cases of congenital heart-block due to anatomical discontinuity of the conductive system of the heart: the bundle of His. Dr. Yater has also been using thorium dioxide for x-ray examination of the spleen and arteries.

Professor GEORGE A. BENNETT of the Department of Anatomy has been investigating the effect of thorium dioxide on tuberculous guinea pigs. He

finds that certain strains of bacilli which cause only localized lesions in the lungs become more destructive and produce generalized tuberculosis if the animal has been previously treated by thorium dioxide.

Dr. THEODORE KOPPANYI, of the Department of Pharmacology, and his associates discovered a very specific and sensitive test for veronal and its derivatives. This test already has found wide clinical application. Also this test made it possible for the first time in the history of pharmacology to follow the fate of the drug in the human and animal body and account for almost every milligram injected.

Dr. J. BAY JACOBS of the Department of Obstetrics investigated the effects of the much discussed new drug, dilaudid, in labor and found that it possesses no advantages over morphine.

Present Papers on Mammalogy.—Papers by five members of the Bureau of Biological Survey were presented at the fifteenth annual meeting of the American Society of Mammalogists, held at the Biological Institute of Harvard University, in Cambridge, Mass., May 9 to 13. A paper by VERNON BAILEY dealt with *The importance of types and type localities in the study of mammals* and one by E. A. GOLDMAN discussed *The isolation factor in the evolution of species*. Dr. H. H. T. JACKSON, a member of the society's board of directors, spoke on *Preservation of teeth of larger mammals*. The title of an address by Dr. T. S. PALMER was *Are there sixty thousand antelope in the United States and Canada?* Illustrated with slides, a paper by CHAS. C. SPERRY, of the Bureau's Denver (Colo.) food-habits research laboratory, dealt with the subject, *Fall food habits of coyotes, a report of progress, 1932*. FREDERIC WINTHROP, JR., of the Museum of Comparative Zoology, spoke on *A collecting trip Across Northern Mexico*, made last winter in company with VERNON BAILEY, of the Biological Survey. The report was illustrated with motion pictures and slides. The Biological Survey was also represented by its associate chief, W. C. HENDERSON, and by E. A. PREBLE, chairman of the society's editorial board, and Mrs. VIOLA S. SNYDER, treasurer of the society.

VERNON BAILEY, chief field naturalist of the Biological Survey, was elected president of the society for the coming year.

NEWS BRIEFS

The construction of the building and dome of the new 15-inch photographic refractor of the Naval Observatory is nearly completed. The objective, of the triplet type, is being made by ROBERT LUNDIN and the mounting by Warner and Swasey.

During the months of March and April, ALBERT E. SCARLETT, of Mount Vernon, N. Y. (amateur radio station W2CC), through whom radio messages from the Watheroo Magnetic Observatory in Western Australia are received, succeeded in establishing a long record for daily contacts with H. M. COOPER, Glenelg, South Australia (VK5HG). By April 13, he had succeeded in securing sixteen or seventeen such contacts without a miss, a remarkable feat considering the low power of both stations.

The following officers were elected at the 54th Annual Meeting of the Biological Society of Washington on April 29:—*President*, C. E. CHAMBLISS; *Vice-Presidents*, C. W. STILES, T. E. SNYDER, H. C. FULLER, T. H. KEARNEY; *Recording Secretary*, S. F. BLAKE; *Corresponding Secretary*, JOE

S. WADE; *Treasurer*, F. C. LINCOLN; *Members of Council*, W. R. MAXON, A. A. DOOLITTLE, I. N. HOFFMAN, E. P. WALKER, J. SHILLINGER.

PERSONAL ITEMS

Commander R. S. PATTON has been appointed head of the U. S. Coast and Geodetic Survey. Commander Patton has been connected with the Survey since 1904.

Professor ELLIOT R. CLARK of the University of Pennsylvania delivered an address to the faculty and students of the School of Medicine, George Washington University on Saturday, April 29. Dr. Clark's subject was *Spontaneous activity of capillaries.*

Dr. J. S. AMES, chairman of the National Advisory Committee for Aeronautics has appointed Dr. H. C. DICKINSON of the U. S. Bureau of Standards chairman of the special subcommittee on standardization of methods of rating aircraft engines. One of the principal functions of this subcommittee will be the correlation of requirements for the testing of civil and military aircraft engines.

J. A. FLEMING, acting director, Department of Terrestrial Magnetism, represented the Carnegie Institution of Washington at the dedication of the George Eastman Research Laboratories of the Massachusetts Institute of Technology on May 1.

Director HORACE M. ALBRIGHT of the U. S. National Park Service, was one of the principal speakers at the first camp exposition of the Washington Y.M.C.A. the evening of May 6. Dr. HAROLD C. BRYANT, Assistant Director, showed lantern slides of parks and monuments.

EARL A. TRAGER, geologist in the Washington office of the U. S. National Park Service, is now in Chicago installing the national parks and monuments exhibits at the Century of Progress. In addition to the Service's exhibit in the Government Building there will be eight dioramas in the Hall of Science displaying the earth sciences as exemplified in the national parks. These eight dioramas were prepared at Park Service Field Headquarters in Berkeley under the direction of Senior Park Naturalist and Forester ANSEL F. HALL.

VERNE E. CHATELAIN, historian, and FRANK A. KITTREDGE, chief civil engineer of the U. S. National Park Service, recently visited the Morristown Historical Park area to investigate development needs and to look into the matter of suitable boundary lines.